U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

PB-250 169

Handling, Treatment and Disposal of Wastewater Sludge

USSR-US Jt Com on Coop in the Field of Environmental Protection

Prepared for

Environmental Protection Agency, Washington, D C

16 May 75

BIBLIOGRAPHIC DATA SHEET

1. Report No.

2.

3. Recipient's Accession No.
PB-258 168

4. Title and Subtitle
Handling, Treatment and Disposal of Wastewater Sludge

5. Report Date
16 May 75

6.

7. Author(s)

8. Performing Organization Rept. No.

9. Performing Organization Name and Address
Union of Soviet Socialist Republics-United States Joint Committee on Cooperation in the Field of Environmental Protection

10. Project/Task/Work Unit No.

11. Contract/Grant No.

12. Sponsoring Organization Name and Address

13. Type of Report & Period Covered

14.

15. Supplementary Notes Papers presented at the USA/USSR Symposium on Handling, Treatment and Disposal of Wastewater Sludge, Held at Moscow, USSR, on May 13-16, 1975. Sponsored in part by Environmental Protection Agency, Washington, D.C.

16. Abstracts
CONTENTS: Policy on municipal sludges; Sludge incineration systems for purification and resource recovery; Management of oil sludge from a refinery waste water treatment plant; Modern state and principal trends in technology development for Washington sludge treatment; Management and disposal of residuals from treatment of industrial wastewaters; Sludge considerations in the development of industrial effluent; Thickening and dewatering of waste water sludges by vibro filtration method; Municipal sludge management research program in the U.S.A.; Inorganic suspended sludge dewatering; Dewatering of sewage sludge by means of centrifuges; Thermal drying of dewatered sewage sludge; Aerobic stabilization of activated sludge; Thickening of sludges; Dissolved air flotation thickening as practiced in the U.S.; Utilization of municipal sludge in agriculture; The dependence of dewatering process on aqueous properties of sludges; Main principles of selection of wastewater sludge treatment methods depending on its properties; Processing and disposal of industrial sludges from

17. Key Words and Document Analysis. 17a. Descriptors

*Sewage treatment,
*Sludge disposal,
*Water pollution control,
*Meetings,
Government policies,
Incinerators,
Petroleum refining,
Industrial wastes,
Filtration,
Dewatering,
Centrifuging,
Flocculants,
Flotation,
Sludge drying,
Fertilizers,
Iron and steel industry,
United States,
USSR.

17b. Identifiers/Open-Ended Terms

Sewage irrigation.

17c. COSATI Field/Group 13 B

18. Availability Statement
National Technical Information Service
Springfield, Virginia 22161

19. Security Class (This Report)
UNCLASSIFIED

20. Security Class (This Page)
UNCLASSIFIED

21. No. of Pages
150

22. Price
6.75/3.00

PB 260 169

[illegible]

USSR-USA JOINT COMMITTEE
ON COOPERATION IN THE
FIELD OF ENVIRONMENTAL PROTECTION

USA/USSR SYMPOSIUM

HANDLING, TREATMENT AND DISPOSAL OF WASTEWATER SLUDGE

MOSCOW, USSR

May 13-16, 1975

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best available copy.

PREFACE

The first cooperative USA/USSR symposium on municipal and industrial wastewater sludge was held in Moscow, USSR from May 13 thru May 16, 1975. This symposium was conducted in accord with the protocol of the Third Session of the Joint USA/USSR Commission held in Moscow on December 17, 1974.

This symposium was sponsored under the auspices of the Working Group on the Prevention of Water Pollution from Municipal and Industrial Sources. The United States delegation was headed by Harold P. Cahill of the United States Environmental Protection Agency and the Soviet delegation was headed by Professor S. Yakovlev of the All Union Research Institute on Water Supply and Sewerage.

Of the eighteen papers, sixteen are reprinted in English in this volume. The paper presented by Turovsky was never furnished. The paper scheduled for presentation by Ostrovsky was canceled and, to date, we have not received copies of these two papers.

This volume is reprinted in English in accord with the protocol signed by the delegation leaders on May 26, 1975 in Moscow, USSR.

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U.S. ENVIRONMENTAL PROTECTION AGENCY
POLICY ON MUNICIPAL SLUDGES

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PREPARED FOR

U.S./U.S.S.R. SEMINAR, "HANDLING,
TREATMENT AND DISPOSAL OF SLUDGES"
MOSCOW, U.S.S.R.

MAY 13-27, 1976

U.S. Environmental Protection Agency
Policy on Municipal Sludge

INTRODUCTION

Passage of the Federal Water Pollution Control Act Amendments of 1972 (Public Law 92-500) instituted a broad national program for cleaning up waterways in the United States. The new law creates a program based on three major elements: uniform nationwide standards, enforceable regulations, and a permit program based on effluent limits and geared to specific goals.

The primary aim of the Act is to "restore and maintain the chemical, physical and biological integrity of the Nation's waters." Under the Act each publicly owned treatment works is required to have a permit before discharging to navigable waters. The permit is based on EPA effluent limitations, but more stringent requirements may be imposed to meet approved water quality standards.

The requirements of the Act for higher levels of wastewater treatment will result in a substantive increase in the quantities sludge produced by publicly owned treatment works. Disposition of these sludges is not simple. Methods used in the past are now restricted by specific laws or regulations, or are subject to other constraints in view of new information of environmental significance.

The treatment of wastewaters for pollutant removal produces not only relatively clean water for discharge, but also a significant quantity of residual material. For domestic sewage, treated in publicly owned plants, this residual is essentially organic in nature, although measurable quantities of metal, minerals, and other compounds are also invariably present. Where industrial wastewaters are treated together with domestic sewage, the potential for additional foreign materials in the resultant sludge is increased. Further, pathogen organisms in sewage may survive the wastewater treatment process and remain in the residual.

Depending upon the composition of the wastewater treatment plant's sludge, the quantity involved, and the disposal method, disposal of this residual material can have an important impact on the environment. It is essential for wastewater treatment installations to consider the proper disposal of sludge produced as well as the proper disposal of treated wastewater. The requirements of the Federal Water Pollution Control Act, as amended, emphasize the need for environmentally sound means for sludge disposal. The national requirements for secondary treatment for example will not only result in production of a greater quantity of sludge than before, but will also result nationwide in greater quantities and possibly more concentrated forms of contaminates present in the sludge.

Disposition of wastewater treatment plant sludges can affect simultaneously air, land, and water and include considerations of human health, animal health, plant growth, and protection of ground and surface waters from pollution. EPA Regional Administrators consider these matters as they evaluate sludge disposal systems included in the design of publicly owned treatment works for which construction grant applications are made. Despite the still limited information available on the complex issue of sludge utilization and disposal, the need for definition of a base line of acceptable practice remains.

BACKGROUND

The effluent limitation applicable to municipal wastewater treatment plants is secondary treatment. EPA has defined secondary treatment as a maximum 30 day average of 30 mg/l of 5 day biochemical oxygen demand and suspended solids, and a maximum 7 day average of 45 mg/l of BOD_5 and suspended solids. This higher degree of treatment will result in generation of more sludge in municipal treatment works. Table I shows the estimated quantities of sludge currently being produced in comparison with the quantities of sludge anticipated after implementation of secondary treatment.

It should be noted that the information in Table I is reported in terms of dry weight of sludge. This is done because the dry weight affords a convenient means of providing a consistent comparison of different types of sludges. Actually the sludge occurs, with various amounts of water, as a liquid slurry ranging to a drier filter cake. Table II shows typical volumes of sludges from various treatment processes.

There are approximately 22,000 municipal plants in the United States today. About 5,000 of these plants are wastewater treatment ponds, which contain the sludge within the pond and are only infrequently emptied. The number of municipal plants generating sludge routinely is approximately 17,000. Table III shows a distribution, by volume of wastewater treated, of these plants.

The current disposition of municipal sludge is not precisely known. There is, however, sufficient data to permit a reasonable estimate of the disposition practices actually being used at the present time. Table IV shows these estimates.

TECHNICAL APPROACH

EPA, continuing the work of its predecessor agencies, has been developing environmentally acceptable methods for the management of municipal sludge since the enactment of the first Federal water pollution control laws. The initial phases of the research program were concerned with the characteristics and dewatering properties of primary and secondary sludge because of the need to dewater sludge for ultimate disposal. The current program emphasis has shifted toward the development of improved technology for returning the sludges to the environment in an ecologically acceptable manner. Also, the agency is requiring new measures, such as source control and pretreatment, which should reduce the heavy metals problems associated with sewage sludges.

The agency has been aware of the growing sludge disposal problem and the need to verify and expand the technology that is now being utilized.

For example, a long-term land application project has been directed at determining the beneficial uses of sludge for strip mine reclamation and for soil enrichment in crop production. Because of the potential human health hazards from heavy metals uptake in plants, these studies have carefully monitored the heavy metals uptake in various forest and green crops.

A large increase in the amount of sludge generated has occurred with the use of chemical precipitants for nutrient control in the upgrading of secondary treatment facilities. The agency has been actively developing new technology for solving the problem, including recovering and reuse of the chemical additives.

EPA will continue its comprehensive research program for municipal wastewater sludge processing, utilization, and disposal. This program will concentrate on demonstration of technologies which will recycle for use sludges, or recover residual contained in sludges. It seems likely that within the next five years a new generation of more nearly optimum sludge disposal or utilization techniques will be available. In the interim there remains a need for a statement and definition of environmentally acceptable practice based on current knowledge.

In the guidance which EPA has drafted for the Regional Administrators, no attempt has been made to imply that the presently known methods are optimum for sludge utilization or disposal, but rather to state that the adverse environmental factors associated with each method may be tolerable under certain site conditions. The determination of acceptability is based on the environmental assessment and, if necessary, the environmental impact statement for the specific project.

The draft guidance is contained in a technical bulletin entitled Municipal Sludge Management: Environmental Factors. The bulletin is divided into two distinct parts. The first part includes methods in which the sludge is utilized as a resource. The second part includes those methods in which the sludge is not utilized for any beneficial purpose.

Methods which appear to have great future promise, but which have not been used in existing facilities, are not included in this list. As these developing methods are demonstrated in practical use, and as supporting information is obtained, they will be added to the list of acceptable methods. Because it is a policy of EPA to encourage and, where possible, assist in development of new advanced wastewater treatment procedures, Federal grants funds may be awarded for the construction of sludge utilization or disposal facilities not in the bulletin, provided sufficient information is presented by the grant applicant to determine that these facilities would meet applicable statutory and regulatory requirements and would be environmentally acceptable.

The technical approach is similar for each of the four methods listed in the bulletin. The criteria consider existing regulations, intermedia environmental effect, protection of public health, and monitoring. Wherever possible maximum use has been made of existing EPA regulatory material or guidelines.

Another aspect of sludge management which is of great importance is cost-effectiveness. This facet of sludge management, however, is not covered in the draft technical bulletin on environmental acceptability.

The proper operation, maintenance and monitoring of sludge utilization or disposal practices is essential to ensure that adverse environmental effects do not result. Grant applicants must demonstrate that they will have managers, operators, and resources necessary to achieve and maintain the required performance on a continuing basis.

KEY ISSUES

In assessing the environmental acceptability of sludge utilization or disposal methods, it soon became clear that there were certain problem areas which occur regardless of the particular option being studied. For example the occurrence of trace amounts of so-called heavy metals in sewage sludges places severe restrictions on the option chosen. Although the severity of the metals problem varies from method to method, heavy metals are a sufficiently pervasive problem to warrant serious action by municipalities to minimize the amounts of such metal introduced into sewage collection systems. Unfortunately, we know very little about the long-term health effects of trace amounts of these metals. Similarly, we know little about the bioconcentration of these metals in the food chain and their effects on man.

While source control and pretreatment of industrial waste introduced into municipal treatment works will materially assist in reducing the quantities of such metals, there is information which indicates metals also come from other relatively uncontrolled sources. Corrosion of metallic plumbing elements in soft water areas may be a source. Street run-off may be a source in areas where there are combined sewers.

Another pervasive problem is the unevenness of regulatory control exercised over the various sludge management options. This ranges from ocean disposal (which is very strictly controlled and which cannot legally be done at the present time without a permit) to land application of sewage sludge which has no Federal control and in some States virtually no State control. For this reason the bulletin contains extensive criteria on land application, but references existing regulations in the ocean disposal area. To those unaware of this background material the bulletin appears much more stringent with regard to land application than it is for ocean disposal. In fact, there has been extensive effort to assure proper balance in this area. While balancing the environmental risk is the goal, equality of environmental risk could not be obtained because of the differing media and management options.

LAND APPLICATION

The only sludge utilization method recognized in the technical bulletin is land application. Because land application of sludge conserves organic matter, nitrates, phosphates, and certain essential trace elements, such utilization encouraged when it is supported by the environmental assessment.

Specifically, stabilization of sludge and subsequent land application for enhancement of parks and forests and reclamation of poor or damaged terrain should be considered for the utilization of sludge. Application of stabilized sludge to agricultural lands on which crops entering the human food chain will *not* be grown may also be regarded as an environmentally acceptable method of sludge disposal. However, application of sludge on land which crops entering the human food chain will or may be grown must be examined closely in terms of hazards to human health and future land productivity. Priority consideration should be given to non-agriculture uses.

The bulletin describes in some detail the information required for design and evaluation of a site for land application of sludges. The nature and extent of this information must, however, be tailored to the size of the project and a relative impact anticipated for the project. Information should be obtained on sludge characteristics to determine nutrient values, heavy metals, and other constituents which may be economically recycled or cause environmental damage. Of course, where there is no existing plant, determining the sludge characteristics would be difficult if not virtually impossible. In this case reasoned estimates must be made and the monitoring program intensified to ensure satisfactory performance. Soil information, such as cation exchange capacity, pH, and background heavy metals, is important where the sludge is to be applied to agricultural lands. Extensive background information on this subject is available through Department of Agriculture soil surveys. Finally the ground water characteristics in the area where the sludge will be applied should be determined. Normally this will consist of a thorough review of existing information supplemented as necessary by an investigation of soil and ground water conditions.

The general requirements for land application of sludge include preventing odors, protecting public health, protecting ground water, and adequate monitoring. Experience has shown that public reactions to nuisance odor conditions is one of the most limiting factors in land application of sludges. For this reason the sludge must be adequately stabilized prior to land application. The stabilization method most frequently used is anaerobic digestion, but there are numerous other acceptable methods. Either a high degree of reduction of volatile matter, or chemical treatment to inhibit bacterial action, is necessary. Other methods to prepare sludge for land application, such as anaerobic digestion, chemical treatment, heat stabilization, or heat drying, also may be used provided public health factors and nuisance potential are no greater than would be associated with anaerobic digestion. The degree of volatile reduction achieved by anaerobic digestion is generally not less than 40 percent to achieve a stabilized sludge. Where other stabilization methods are used this degree of reduction may not be applicable.

Chemical treatment typically does not significantly reduce volatile matter but the rate of decomposition is slowed so that any odors are dissipated at very low concentrations. Odor conditions may occur in time if the rate of anaerobic decomposition increases, such as by neutralization of the chemical treatment. In this case sludge should be incorporated into the soil. At some plants the stabilized sludge is spread on drying beds or temporarily stored in sludge lagoons. These methods decrease potential odor problems from sludge applied to land since additional stabilization occurs with time. Digested sludge can also be further stabilized by various composting systems.

For some projects it may be necessary to achieve additional pathogen reduction beyond that obtained by stabilization. The following methods have been reported to be successful: 1) Pasteurization for 30 minutes at 70 degrees centigrade. 2) High pH treatment, typically with lime, at a pH greater than 12 for three hours. 3) Long-term storage of liquid digested sludge for 60 days at 20 degrees centigrade or 120 days at 4 degrees centigrade. 4) Complete composting at temperatures above 55 degrees centigrade as a result of oxidative bacterial action and curing in a stockpile for at least 30 days.

Public access to sites practicing land application of sludge must be controlled by either positive barriers such as fences or by remoteness of the site. Where this is not done additional pathogen reduction methods, as outlined above, should be used. The site also must be designed to prevent pollution of ground water resources and to prevent surface water run-off pollution of streams.

There are a varity of methods used to apply the sludge to the land. Liquid digested sludge may be applied to the land by using a spreading method such as a tank truck, plow injection, or ridge and furrow spreading. Dried or dewatered stabilized sludge, or composted material from digested sludge, may also be spread on the land. If desired, the sludge can be incorporated into the soil by plowing, discing, or similar methods. Spray application of digested sludge to the land is acceptable when the transport of aerosols beyond the boundaries of the application area is minimized through such means as the use of low pressure sprays, or spray nozzles located close to ground level and directed downward, or through remoteness of the site.

Sludge application rates can be estimated based on experience, site operating data, or test plot data. Nitrogen substances usually limit annually application rates. The rate of sludge application to agriculture land must be consistent with the use of nitrogen by agronomic crops to prevent nitrate pollution of ground water. The information required to establish a sludge application rate includes: 1) total and inorganic nitrogen content of the sludge, 2) nitrogen, phosphate, and potassium requirements of the crop being grown, and 3) a soil test for available phosphate and potassium. Supplemental fertilizer, especially potassium, may be needed to optimize crop production. The sludge application rates should be such that the total amount of plant available nitrogen added is no greater than twice the nitrogen requirement of the crop grown. It is possible that the presence in the sludge of certain salts, phosphate compounds, or metals, or other materials may also limit application rates in specific instances. The sludge is generated relatively constantly throughout the year. The application rate must therefore be harmonized with the crop growing season. A mass balance is necessary to determine the amount of sludge storage required during intervals when the sludge is not applied to the land.

The draft technical bulletin requires the grant applicant to develop and implement a plan for adequate monitoring of each land application site where the application rate will exceed five dry tons per acre per year, for liquid digested sludge, or 50 dry tons per acre over a three year period for dried or dewatered sludge. Use of bagged sludge fertilizer products for the retail market will not require site monitoring. The site monitoring plan must be specifically designed for applicable local conditions and it includes consideration of heavy metals, persistent organics, pathogens, and nitrates in ground water, surface water, sludge, and soils.

The operation and monitoring data of the system must be periodically reviewed to ensure satisfactory performance. Where there is not a local or State program for this purpose, an alternative independent review will be necessary. This could be done by a consultant or by an agricultural extension service.

The operation and monitoring data of the system must be periodically reviewed to ensure satisfactory performance. Where there is not a local or State program for this purpose, an alternative independent review will be necessary. This could be done by a consultant or by an agricultural extension service.

In additional to the foregoing general requirements, the application of sludge to agricultural lands which may be used to grow crops must be accomplished so as to ensure crop land resources are protected and harmful crop contaminants do not enter the human food chain. Some projects, however, are clearly of minimal concern, either because of their relative size and impact or because they are controlled by other means. An environmental assessment involving testing of the sludge for heavy metals and pathogens will verify this is the case for the particular project. In these cases of lesser concern, the project should conform with the foregoing general requirements, but need not necessarily conform with each of the specific limits and monitoring requirements. Example of this type of project include:

1. Small projects where the designed flow of the publicly owned treatment works is less than one million

gallons per day, particularly where there are no industrial users of the system and the application rates are low.

2. Where the sludge is applied to city owned or government controlled land dedicated to receive sludge.

3. Where the existing sludge operation is a commercial activity, producing bagged products. In this case there should be a temporary variance for nonconforming sludges with an approved implementation schedule established to conform with applicable limits such as metals and pathogens. New projects should not be exempted.

The agriculture research service of the U.S. Department of Agriculture has suggested the following interim criteria. The limits are based on experiments directed at the determination of levels of heavy metals which are toxic to plants. They are designed to keep down the level of heavy metal being absorbed by the plants. Because of the great uncertainty concerning the appropriate level of intake by humans of these heavy metals as part of their diet, EPA cannot say that these levels constitute the appropriate levels for human intake. To the extent, however, that the limits represent an attempt to keep the levels of heavy metals at a lower point than otherwise would be the case, these limits will make a contribution to the protection of public health.

No greater total amount of sludge may be applied than calculated by Equation 1 for the particular sludge and soil.

Equation 1

$$\text{Total sludge (dry wt tons/acre)} = \frac{32{,}700\ \text{CEC}}{\text{ppm Zn} + 2(\text{ppm Cu}) + 4(\text{ppm Ni}) - 200}$$

CEC = cation exchange capacity of the unsludged soil in meq/100 g ppm = mg/kg dry wt. of sludge.

This equation limits the heavy metal addition calculated as zinc equivalent to 10 percent CEC. The zinc equivalent takes into account the greater plant toxicity of copper and nickel.

Sludge having a cadmium content greater than 1 percent of its zinc content should not be applied to crop land except under the following conditions:

1) the land areas to receive this sludge are clearly identified in the grant application.

2) There is an abatement program to reduce the quantities of cadmium in the sludge to an acceptable level.

3) The project is reviewed by the U.S. Department of Agriculture and the Food and Drug Administration.

The above criteria apply only to soil that can be adjusted and held at a pH of 6.5 or greater for a period of at least two years after sludge application. The criteria provide one method to limit the amounts of metals in sludges applied to crop lands. Other methods were considered but not adopted at this time, either because they do not address all the factors considered important or it appeared they were not as consistent with the limited data as the above criteria. As more data become available the criteria may change. Accordingly, a high degree of precision should not be inferred for Equation 1 or the cadmium/zinc ratio. Evaluation of borderline cases should be based on the procedures described subsequently, together with an abatement program to reduce the quantities of metals in the sludge. The 1 percent cadmium to zinc ratio is designed to protect against unacceptable cadmium uptake in shallow, low pH, low CEC soils growing leafy vegetables or grains. A cadmium to zinc ratio of up to 1.5 percent could be acceptable where the sludge is applied to marginal lands not being cultivated.

Under certain conditions, specific organisms may survive in the soil for extended periods. Consequently, sludge treated land should not be used for human food crops to be eaten raw until three years after sludge application. Sludge applied to crops which are cooked or processed before consumption, or pastures, or to crops used for forage should test negative for pathogens such as salmonella and Ascaris ova. Forest and pasture crop should not be consumed by animals if these crops are physically contaminated by sludge. Where there is a risk of direct ingestion of the sludge by grazing animals, the lead content of the sludge should not exceed 1,000 mg/kg dry sludge and the cadmium content should not exceed 30 mg/kg dry sludge.

Other sludges may also be acceptable including some which do not in every respect follow in the above criteria. These sludges should only be used under carefully defined and controlled conditions. EPA Regional Administrators will work closely with grant applicants desiring to use these sludges in land application projects.

LANDFILL

Sanitary landfill of sludge, either separately or along with municipal solid waste, is acceptable when supported by the environmental assessment. Sanitary landfills accepting [illegible] sludge must be designed and operated in accordance with EPA guidelines for land disposal of solid waste. Generally, the sludge must be stabilized or dewatered [illegible] land application. If the landfill is not operated by the wastewater treatment authority, a binding agreement is required between that authority and the operator of the sanitary landfill to ensure that the landfill is operated in accordance with the EPA guidelines.

Monitoring requirements for sanitary landfills include ground water observation wells and surface water monitoring where the surface water could be affected directly or by leachate from the sludge landfill.

INCINERATION

Incineration alone is a volume reduction method rather than ultimate disposal. After incineration, ash, either dry or in aqueous water, remains to be disposed of to the land. Ash disposal must be controlled to protect ground water, to prevent dust, and to ensure no runoff to surface water.

The emissions from the sludge incinerator must not be result in violations of ambient air quality standards and must meet the EPA air pollution emission standards of performance. Additionally, EPA has published proposed [illegible] on mercury emissions from the incineration and drying of wastewater treatment plant sludges. The maximum amount would be [illegible] per day. Sludge has been shown to contain trace amounts of metals such as mercury, lead, and cadmium, as well as persistent organic compounds, such as polychlorinated biphenyls. The effects of these compounds which are emitted from the incinerator must be assessed and the sludge should be tested to determine the quantities of such compounds present. If the PCB's exceed the level present in domestic sludge (approximately 10 mg/kg dry sludge) then special measures should be taken to ensure [illegible] destruction of persistent organic compounds. Increased temperatures and residence time increase the efficiency of destruction.

A plan must be developed and implemented to provide for adequate monitoring of each sludge and incinerator. The stack gas emissions from sludge and incinerators must be monitored and, in addition, every [illegible] sludge [illegible] must be periodically tested to demonstrate compliance with EPA standards. Additional monitoring for organic pesticides, PCB's, or heavy metals other than mercury, may be necessary for specific projects.

OCEAN DISPOSAL

Ocean disposal of sewage sludge would be acceptable for treatment works presently using this method only when the sludge meets the EPA criteria and when the disposal method is supported by the environmental assessment. Information available to EPA from permit applications to date indicates that these sludges currently being dumped exceed the criteria and are therefore being dumped under interim permits. One of the conditions of these interim permits is the requirement for an implementation plan to either reduce the toxic materials to meet the criteria or find an alternative method of disposal. Interim permits are granted for one year only and the issuance of new interim permits is based on the progress demonstrated by the permittee on the implementation plan. Currently the EPA will approve only existing dumping sites presently in use for the disposal of particular kinds of waste, unless there is extremely strong evidence in favor of approval of a new location.

CONCLUSION

This paper has presented an overview of the magnitude of the municipal sludge [illegible] in the United States and some of the measures which are being considered to control the utilization or disposal of these sludges. These criteria will be proposed for public comment by all concerned agencies and will be revised to reflect such comments before final promulgation.

Table I Estimated Quantities of Sludge in the United States, dry tons/day

	Current	Secondary Treatment (10 years)
Domestic	10,000	15,000
Industrial users of municipal plants	7,000	10,000
Total municipal sludge	17,000	25,000

Table II Range in Typical Sludge Volumes Produced, gallons of sludge/million gallons wastewater treated

Primary sedimentation	2000 - 3000
Trickling filter	600 - 750
Activated sludge	15,000 - 20000

Table III Volume Distribution of Plants Generating Sludge

Size of plant million gallons/day	Number of plants*
less than 1	11,130
1-5	1,858
5-10	253
10-25	180
25-50	54
50-100	27
Greater than 100	30
Not reported	3,983
Total	17,515

* does not include wastewater treatment ponds

Table IV Estimated Current Disposition of Municipal Sludge

Method	% of Total Sludge
Landfill	25 percent
Ocean dump	15 percent
Incineration	35 percent
Land Application	25 percent

SLUDGE INCINERATION SYSTEMS FOR PURIFICATION AND RESOURCE RECOVERY

by

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Municipal and Industrial Sources

SLUDGE SYMPOSIUM
Moscow
May 13-27, 1975

under

USSR/USA ENVIRONMENTAL AGREEMENT

SLUDGE INCINERATION SYSTEMS FOR PURIFICATION AND RESOURCE RECOVERY

by

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INTRODUCTION

In the treatment of wastes at a sewage treatment plant, following the various dewatering processes waste solids and water still remain for disposal. More stringent laws and codes have reduced freedom of choice in disposing of such waste solids or sludge.

In a study for a midwestern U.S. town, Weller and Condon reported relative costs for various systems as follows:

System	Original Cost	Annual Cost
Dewatering and Incineration of Raw Solids	1.0	1.0
Digesting, Mechanical Dewatering and Land Filling	1.09	1.41
Digesting, Mechanical Dewatering and Incineration	1.41	1.38
Wet Combustion and Effluent Treatment	1.97	1.54

This paper will review sludge incineration and heat treatment for conventional primary secondary systems, and incineration and reclamation for advanced physical chemical systems, particularly as regards their environmental impact.

MHF

The multiple hearth furnace is versatile, although originally developed in 1889 as a furnace to roast pyrites for the manufacture of sulfuric acid. The modern multiple hearth system has been adapted to over 100 proven uses, including:

1. Burning (or drying) raw sludge, digested sludge, and sewage grease;
2. Recalcining lime sludge and waste pond lime;
3. Reclaiming fruit, nut and lumber waste (peach pits, walnut shells, almond shells, sawdust and bark) for charcoal briquettes, and reclaiming cryolite and aluminum smelting operations;
4. Regeneration of spent activated granular carbon and diatomaceous earth;
5. Other uses: mercury, molybdenum sulfide, carbon, magnesium oxide, uranium, yellow cake, nickel

The multiple hearth furnace itself is a simple piece of equipment, consisting primarily of a steel shell lined with refractory on the inside. The refractory can be either castable or in brick form, depending upon the size of the furnace. The interior is divided by horizontal brick arches into separate compartments called hearths. Alternate hearths have holes at the periphery to allow the feed solids to drop into the hearth below. The center shaft, driven by a variable speed motor, rotates the rabble arms attached on each hearth. The rabble teeth on these arms are placed at an angle such that the material is moved inwards and then outwards on alternate hearths. The shaft and rabble arms are cooled by air introduced at the bottom. This air may be recycled as required by the thermal process (Exhibit 1).

The sludge is fed through an inlet in the furnace roof by a screw feeder, or belt and flapgate. The rotating rabble arms and rabble teeth push the sludge across the hearth to drop holes where it falls to the next hearth and continues to the next hearth and the next, until the ash is discharged at the bottom.

The multiple hearth system has three distinct operating zones: the top hearths where the feed is dried to approximately 48% moisture, the incineration/deodorization zone where temperatures of 760°-982°C (1400°-1800°F) are maintained, and the cooling zone where the hot ash gives up heat to the incoming combustion air. The warmed air rises to the combustion zone in counterflow style and the hot combustion gases sweep over the cold incoming sludge, evaporating the sludge moisture to about 48%, at which point a phenomenon called "thermal jump" can occur in the beginning of the combustion zone. This beneficial exchange of energy allows odorfree exhaust gas and temperatures of 260°-593°C (500°-1100°F). The typical temperature profile across the sludge furnace is as follows:

Hearth No.	Approx. Half Capacity °C	°F	Nominal Design Capacity °C	°F
1	354	670	427	800
2	760	1400	649	1200
3	888	1630	899	1650
4	787	1450	787	1450
5	649	1200	649	1200
6	163	325	149	300

Thermal oxidation is reaching new high levels of technology and performance not generally realized even in technical circles. New data recently developed answer favorably for the first time many questions that have surrounded the impact on air quality from such thermal processing systems. In addition, favorable benefits such as energy reclamation and ash utilization from the burning of sludge have become a reality in these sludge processing units.

Sludge Incineration/Reclamation Benefits

- Meets EPA air standards—particulates
- Rated insignificant source of emissions
- Decomposes PCB's (polychlorinated biphenyls)
- Decomposes pesticides—DDT, 2,4,5-T
- Produces ash product—quasi fertilizer
- Recovers resources—CO_2, lime
- Controls heavy metals
- Energy reclamation—Closed Loop Energy System

The most comprehensive study that has been done to date on sludge incineration was by the EPA Sludge Task Force, the report on which was published in August 1972. It included a survey of ten furnaces throughout the United States, including, for example, installations at Monterey and South Lake Tahoe, California. The Task Force study also included a report of the sludge, ash and air emission, and of air pollutants and toxics.

The Monterey sludge incineration building was converted from an existing digester to house the incineration unit. It is located on the edge of Monterey Bay where raw sludge used to be dumped.

The South Lake Tahoe Water Reclamation Plant is one of the most advanced wastewater treatment plants in the world. The solids handling building contains a sludge incineration furnace and a lime recalcination furnace. The EPA Task Force conclusions were:

- Incineration is an acceptable alternative for sludge disposal
- Air emissions acceptable:

  NO_x
  SO_x
  Odors
  Particulates

- Apparent destruction of pesticides/PCB's

The information presented here is principally an update of several key points that were included in the EPA Task Force report.

EPA Task Force Abstract

A Task Force was established within the Environmental Protection Agency to evaluate sludge incineration as an acceptable alternative to sea disposal. Multiple-hearth and fluidized bed furnaces, containing scrubbing devices for particulate removal, were selected for performance evaluation. The sludge, particulate, stack gas, scrubbing liquid, and ash were sampled, and analyzed for heavy metals, pesticides and oxides of nitrogen and sulfur. The results indicated that incinerators are capable of achieving low emission concentrations for the common pollutants. Particulate samples showed a measurable concentration of lead. The ash samples normally showed a higher concentration of the heavy metals when compared with the sludge samples; however, mercury was one of the exceptions and was not detectable in the ash sample and assumed as lost to the stack gases. The pesticides and PCB, present in the sludge, were not detectable in either the ash or the scrubbing water, and indicated complete destruction. The study demonstrated that well designed and operated municipal sewage sludge incinerators can meet the most stringent existing particulate emission control regulation.

Since the Task Force published the report on its findings, there have been new test results pertaining to PCB's, pesticides, lead and mercury. The new data show that the air quality impact can be even further reduced over the Task Force data. In addition, the fate of PCB's became the pivotal issue of the report insofar as fuel conservation was concerned. These concerns have now been relaxed.

The Task Force report recommended that, to be certain of complete decomposition of PCB's found in a sludge furnace, exhaust gases should be raised to 871°C (1600°F) for two seconds.

The Task Force further reported that PCB's were found to range from "not detected" in mountainous areas to 105 PPM in industrial areas where PCB's were used in manufacturing processes. The 871°C (1600°F) temperature requirement, if imposed, would have meant as much as a four-fold increase in the fuel cost of a typical sludge incinerator at that time.

As soon as a copy of the preliminary Task Force report was received, in February 1972, Envirotech immediately undertook an independent study and found virtually complete destruction of PCB's at 593°C (1100°F) in only one-tenth of a second, and 95% decomposition under normal operations. This information was presented to the EPA and in November 1974 the draft EPA Technical Bulletin on Sludge Disposal revised the guidelines as follows: (1) check to determine if the PCB content in sludge exceeds 10 milligrams per kilogram, and (2) if it does, use a process that assures PCB decomposition. Since the new data showed that this can be achieved at the normal operating parameters of a multiple hearth furnace, no extra fuel is required to eliminate the PCB's even when the sludge contains more than 10 milligrams per kilogram.

The tests that led to this new guideline were conducted by injecting PCB's into the sewage sludge at the San Mateo, California furnace:

- 4000 PPM of Therminol FR-1 was injected into the sludge feed.
- The furnace was operated at normal temperatures with internal temperatures of
  815°C (1500°F) to 926°C (1700°F)
- Four different afterburner temperatures were used to develop specific decomposition data:
  371°C (700°F)
  427°C (800°F)
  482°C (900°F)
  632°C (1170°F)
- The analysis was done by certified independent laboratories.

The results showed that 95% of the PCB's were destroyed at 371°C (700°F) using 0.1 second exhaust gas detention time. At 593°C (1100°F), 99.9% of all PCB's were destroyed, also at an exhaust gas detention time of 0.1 second.

What is the significance of PCB in sludge? Perhaps it would be helpful to review briefly some background information on PCB. PCB's have some unique properties that have made them very useful in industrial applications for the last forty years. PCB's were first produced commercially in the U.S. in 1929. Since then they have been produced by one U.S. manufacturer and several manufacturers outside the U.S.

The main properties that distinguish PCB's are: they are inert chemicals; they are insoluble in water; they are adhesive; they are extremely heat resistant; and they are toxic to many organisms. Chemically, they are very similar to the well known chlorinated hydrocarbons in pesticides. Due to their remarkable stability, PCB's have found many uses, particularly in industry.

The major use of PCB's has been the electrical equipment industry, followed by heat transfer systems, use as hydraulic fluid, and, finally, use as plasticizers which originally, but no longer, included carbonless carbon paper, and in paints and glues. In 1966, PCB's were first identified as being present in some food products and, since, have been found throughout the environment.

Based on these findings, the sole producer of PCB's in the United States voluntarily limited production of these chemicals in 1971. The latter three of these uses have been severely limited and suitable substitutes have been found for the PCB's. At this time, the U.S. government is recommending the use of PCB's only in electrical equipment, such as transformers and capacitors, which presently have no suitable substitute for PCB's.

A U.S. government interdepartmental task force on PCB's identified where PCB's exist in the environment. It was estimated that in North America the air environment contains 20,000 tons of PCB's, land environment, 290,000 tons, and the water environment, 30,000 tons. These totals represent a great majority of the PCB's that have been produced in the last forty years. Worldwide totals for these three sectors of the environment would run much higher. Significant to this report is that the government pinpointed the principal means of cycling through the environment for PCB's as being in waste water systems.

The cycle consists of waste streams, receiving waters, fish, animals and, finally, man. PCB's, like their close pesticide relatives, the DDT, DDD, dieldrin chlorinated hydrocarbons, tend to concentrate in the higher levels of the food chain and in the fatty tissues of animals. The cycle begins with waste streams from industrial manufacturing or accidental spills into sewers or streams. From there the PCB's enter receiving waters were aquatic organisms ingest them, and as mentioned above they concentrate in the top of the food chain. Also, wildlife, which increasingly serve man as an early warning system, take the PCB's and concentrate them in their bodies when they consume water laced with PCB. Finally, the chemicals find their way into man. The U.S. government does not believe that PCB's represent an immediate threat to human health. However, this tendency to concentrate in the food chain, plus the long lived characteristics of PCB's make them a long range threat. The U.S. government has recognized them as such and some New York reports show a direct correlation in fish with age.

In September 1971 a United States Geological Survey report made headlines in the newspapers across the U.S. A survey of streams and lakes in 39 states detected PCB's in 17 of the 39 states. In many places where PCB's would not be expected to exist, such as remote lakes and rivers, scientists were surprised to find PCB's present.

This omnipresence, coupled with the non-biodegradability, is obviously the reason the U.S. EPA is concerned about the fate of PCB in sludges. Fortunately, the current sludge incineration technology has been

engths are about equal to driving a U.S. car one-tenth of a mile.

The test results from San Mateo and Palo Alto were studied by EPA personnel concerned with solid waste and the disposition of residuals.

EPA concerns involved excess DDT which has been banned in the U.S. and the disposition of the pesticide 2,4,5-T. The Solid Waste Division of EPA was interested in the possibility of injecting DDT into sludge as a means of processing DDT through the furnace to remove it from the environment. The EPA contracted for tests to be performed by Versar, Inc., an independent laboratory. Following pilot scale tests, full scale tests were run at the Palo Alto installation. DDT was injected into the sludge (Exhibit 5) at the rate of [illegible] grams per hour. The ash at the bottom of the furnace contained [illegible] grams/hour. In the scrubbings with an afterburner operating there was [illegible] grams per hour and [illegible] grams per hour were contained in the scrubber water which is returned to the headworks. The overall removal or decomposition efficiency was determined to be [illegible]. It was concluded that any DDT that is normally contained in the sludge is destroyed in the furnace, and that additional DDT up to [illegible] that might be added to the sludge would also be similarly decomposed. Similar tests were conducted for 2,4,5-T with similar results: [illegible] decomposition (Exhibit 6).

There has been some expressed concern about the fate of heavy metals that might be contained in sludge. The EPA contracted for additional tests at Palo Alto as to the fate of lead and mercury in the sludge. In the case of lead, there was plenty in the sludge since electronic industry wastewater is treated at the Palo Alto municipal plant. It was found, much to the surprise of many people, that the lead in sludge is not volatilized into the atmosphere.

The sludge input contained 5370 grams/day, the ash from the furnace contained [illegible] grams/day. Scrubber water picked up [illegible] grams/day and only 67 grams/day entered the atmosphere through the exhaust stream. Overall, removal efficiency was found to be [illegible] (Exhibit 7).

The mercury results are probably even more surprising. The EPA Task Force report assumed, as had others, that all the mercury in the sludge was volatilized and went into the atmosphere. However, the Versar testing contractor developed different figures after studying the pesticide results, and obtained EPA support for tests on the fate of mercury in sludge when incinerated. The sludge feed contained [illegible] grams per day of mercury, but a high percentage—[illegible] grams per day—of that mercury went through the furnace with the ash. As mentioned previously, the EPA Task Force found no measurable quantity of mercury in the ash. The scrubber water which is returned to the plant headworks contained [illegible] grams/day. Only [illegible] grams per day went into the atmosphere. Overall, the process controlled [illegible] of the mercury (Exhibit 8).

LIME RECLAMATION

In these energy and material conscious days, reclamation is all important. Reclamation in the multiple hearth furnace is a normal operating procedure. For instance, the Lake Tahoe Water Reclamation Plant uses a separate multiple hearth furnace to recalcine or reclaim lime that is used in the treatment process. Since this is a manufacturing process, that is, taking the lime-rich sludge and reclaiming the valuable lime treatment chemical, it does not fall under the sludge furnace air quality regulations. A further benefit of reclaiming lime is that there is a unique opportunity to lower emissions to the atmosphere in the process. When lime is added to facilitate settling of the solid matter, the alkalinity pH of the wastewater is raised substantially. In order to reduce the pH, the exhaust gases from the furnace are highly cleaned in the methods already described; they are not released to the atmosphere but are reused. To capture the CO_2 that is required by the process, the gases are compressed and bubbled into the bottom of a recarbonation basin where the CO_2 and trace components in the gases are transferred to the wastewater. Thus the gases are further scrubbed clean. This system has been in operation at the South Lake Tahoe Water Reclamation Plant since 1968.

ENERGY RECLAMATION

A further industry development is that of energy reclamation from sewage plants. In addition to the reclamation of the fuel value of sewage sludge to reclaim chemicals on site for reuse, a further step has been taken in three municipal plants currently under construction involving the use of third generation multiple hearth furnace systems which we call Closed Loop Energy Systems (Exhibit 9). In these systems a sludge heat treatment step is installed to break loose the water bound in the biological cells to enable normal dewatering equipment (vacuum filters or centrifuges) to be used to obtain up to a [illegible] increase in the normal solids content of the sludge. This brings the sludge to a fuel value approximately equal to that of soft coal. The heat treated sludge is then processed through a similar but differently designed furnace to convert itself to a usable but potentially useful ash without the need for auxiliary operating fuels and with sufficient heat left over to provide process heat and steam at the treatment plant.

Three sludge handling and disposal systems, designed with a "closed circuit energy loop" to conserve fuel, are currently under construction in the U.S. for Granite City, Illinois, Chesapeake-Elizabeth, Virginia, and the Western Branch Plant at Prince Georges County, Maryland.

Granite City, Illinois

At Granite City the existing wastewater facility is currently being upgraded with activated sludge treatment to handle the 10 MGD flow and to treat sludge in a "recuperative" BSP system. The influent consists primarily of domestic waste with a small industrial component.

This system includes:

- Two 4000 GPH BSP Heat Treatment units to thermally condition hydrous sludges using waste heat recovered from the furnace.
- One 16'9" ø x 7 hearth furnace designed to reduce 11,000 lb/hr of cake to 1000 lb/hr inert ash without use of support fuel.
- One heat recovery boiler to convert the furnace's 16.9 million BTU/hr of waste heat to 8,100 lb/hr steam for thermal conditioning of the raw sludge.
- (The Eimco/BSP system also includes an 18 GPM BSP Scum Concentrator to segregate grease and fibrous trash and to put it into the furnace as fuel at a controlled rate, and an Aero Impingement scrubber to control emissions.)

The $10 million expansion at Granite City will also include two Eimco 60' ø x 10' primary clarifiers, two Eimco 70' ø gravity sludge thickeners, and an Environmental Operating Services contract for a startup and training assistance program.

Chesapeake-Elizabeth, Virginia

The Chesapeake-Elizabeth waste treatment facility in Virginia, one of many being executed for the Hampton Roads Sanitation District, includes:

- Two 70' ø x 10' Eimco Sludge Thickeners.
- One 6000 GPH BSP Heat Treatment unit.
- Two 16'9" ø x 7 hearth BSP furnace systems and an Environmental Operating Services startup and training assistance program.
- Two heat recovery boilers to convert 3,010,000 BTU/hr. of waste heat into 6,000 lb/hr of steam for the BSP Heat Treatment Process.

Western Branch, Maryland

The Western Branch facility at Prince Georges County, Maryland is the largest of the three new "Closed Energy Loop" projects. It consists of upgrading an existing 10 MGD plant to reduce the sludge volume containing 61,700 pounds of dry solids per day over 90% in a virtually "fuel-less" system. The plant primarily processes municipal waste with a small industrial component. It includes two 6000 GPH BSP Heat Treatment systems and two 16'9" ø x 7 hearth BSP furnaces. The 8000 lb/hr waste heat recovered from the autogenous combustion is 25% more than the 6400 lb/hr necessary to power the heat treatment system.

The economics of the CLES are based on the fact that the combustion in the furnace containing the closed loop concept is self-sustaining. The excess heat from the combustion is sufficient to run the heat treatment system's heat treatment requirements. Therefore, the fuel required in CLES is essentially zero (Exhibit 9).

Regarding the actual cost comparison between the Closed Loop Energy System and the conventional system (Exhibit 10):

1. Costs include both operating and amortized capital costs of installed heat treatment and multiple hearth furnace systems.
2. All costs have been reduced to "dollars per ton" of dry solids, and include all the actual solids generated by a complete primary-secondary treatment flowsheet.
3. Annual costs are computed by multiplying the sludge generated (tons/year) by the cost ($/ton).

The following conclusions are apparent:

1. Despite the fact that a slightly greater quantity of sludge is generated using the Closed Loop Energy System, savings are consistently realized regardless of plant flow;
2. Annual cost savings vary depending on the economies of scale realized. (A particular piece of equipment may be employed at a higher rate of utilization which would affect the savings.) For example, this phenomenon has occurred at the 75 MGD plant flow. Conventional system costs at 75 MGD appear to be somewhat out of line, probably due to lower equipment utilization rates.

ASH AS POTENTIAL FERTILIZER

Other reclamation potential for sludge incineration—in addition to energy and CO_2 recovery—exists in the potential fertilizer value of the ash.

In Japan, more than 10,000 tons of ash from multiple hearth furnaces have been sold on an experimental basis by cities to fertilizer companies for sale in 30 kilo bags. The fertilizer value is

0.1% nitrogen
0.4% phosphate
1.0% potash

To indicate the high potential fertilizer value in ash, a comparison can be made with typical values of nutrients found in wet sludge and used in typical sludge to land projects such as at Denver, Colorado.

Using the value of $0.44 per kilogram ($440 per ton) for nitrogen, $0.88 per kilogram ($800 per ton) for phosphate, and $0.07 per kilogram ($64.00 per ton) for potash, the wet sludge at Denver has been valued at $0.011 per kilogram and $11.11 per ton. By comparison, using the same values, and due to the fact that the ash is more concentrated, the ash from the sludge furnace at Palo Alto, a typical secondary sludge, would have a value of $0.045 per kilogram and $40.80 per ton, four times as much as wet sludge.

The ash from an advanced waste treatment facility such as Tahoe, of course, contains a higher percentage of phosphate. Principally, due to the higher phosphate content of the ash, it has a potential value of $0.088/kilogram and $80.00 per ton.

COSTS

Before closing, a comment about costs based on U.S. experience might be useful.

At the Tahoe Water Reclamation Plant, published figures show an operating cost of $0.134 per kilogram ($117.00 per ton) of dry solids dewatered.

Total operating and capital cost is $0.053 per kilogram ($47.93 per ton) for the sludge incineration process. This amounts to less than 5% of the total cost for complete treatment, which is about $0.109 per cubic meter (40¢/1000 gallons) for the 28,400 cubic meter (7.5 MGD) capacity. Large plant flows would reflect economies of scale and lower costs by as much as one-half.

The Environmental Engineers' Handbook, published in 1974, reports multiple hearth incineration cost for cities of one million population of 14¢ per capita per year and 64¢ per capita per year for cities of 100,000 population.

A 1975 study of one of the large population areas in the U.S.—the Metropolitan Boston area—shows that incineration/reclamation of sludge is the lowest cost and lowest energy use alternative, in comparison to land disposal and wet oxidation. The energy cost alone for land disposal was 60% higher than for sludge incineration.

Fuel costs and labor and material costs have risen sharply since these data were developed but, as mentioned earlier, the new Closed Loop Energy Systems furnaces eliminate the need for auxiliary operating fuel.

The ash is an environmentally superior product for it has been purified of DDT, 2,4,5-T and PCB, as well as many other chemicals found in sludge that are on the EPA toxic chemicals list (e.g., chlordane, dieldrin, endrin, toxaphene). Quantities of heavy metals in excess of allowable would need to be removed through pre-treatment for any fertilizer usage of sludge or ash.

In summary, the new sludge oxidation technology offers the following advantages:

- Meets EPA air standards—particulates
- Rated insignificant source of emissions
- Decomposes PCB's (polychlorinated biphenyls)
- Decomposes pesticides—DDT, 2,4,5-T
- Produces ash product—good fertilizer
- Recovers resources—CO_2, lime
- Controls heavy metals
- Energy reclamation—Closed Loop Energy System

As the USSR and the US move to higher quality levels in both the air and water sectors, the overall environmental impact of technology must be considered. In the allocation of environmental resources in urban communities, advanced thermal processing technology deserves to be fully considered for its resource recovery and purification benefits, as well as for its "disposal" aspects.

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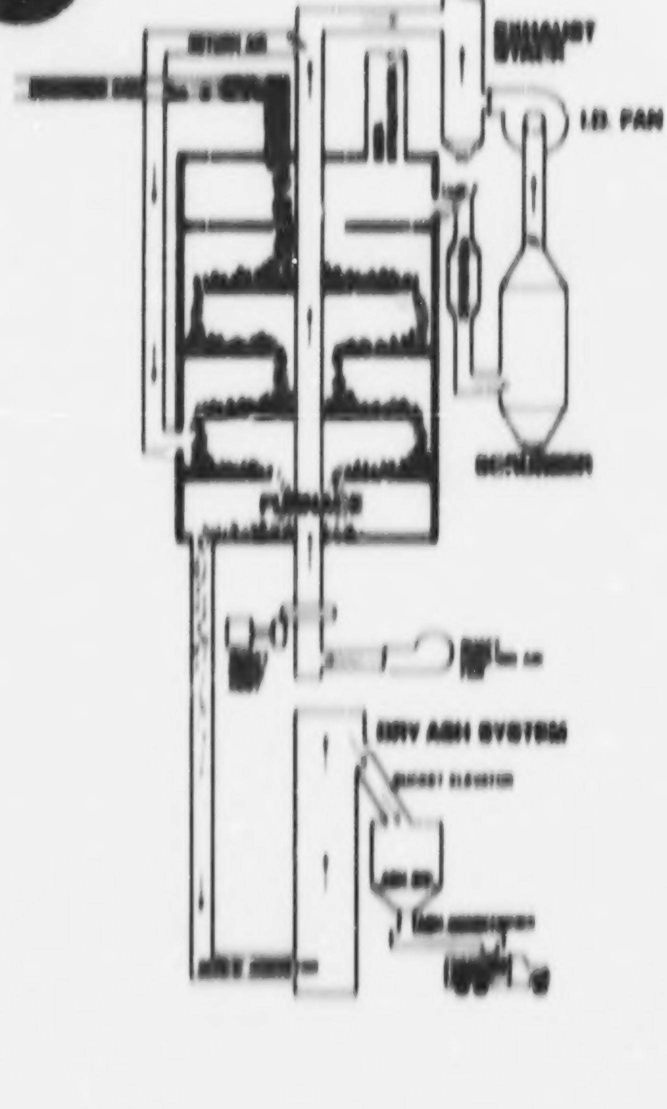
BSP

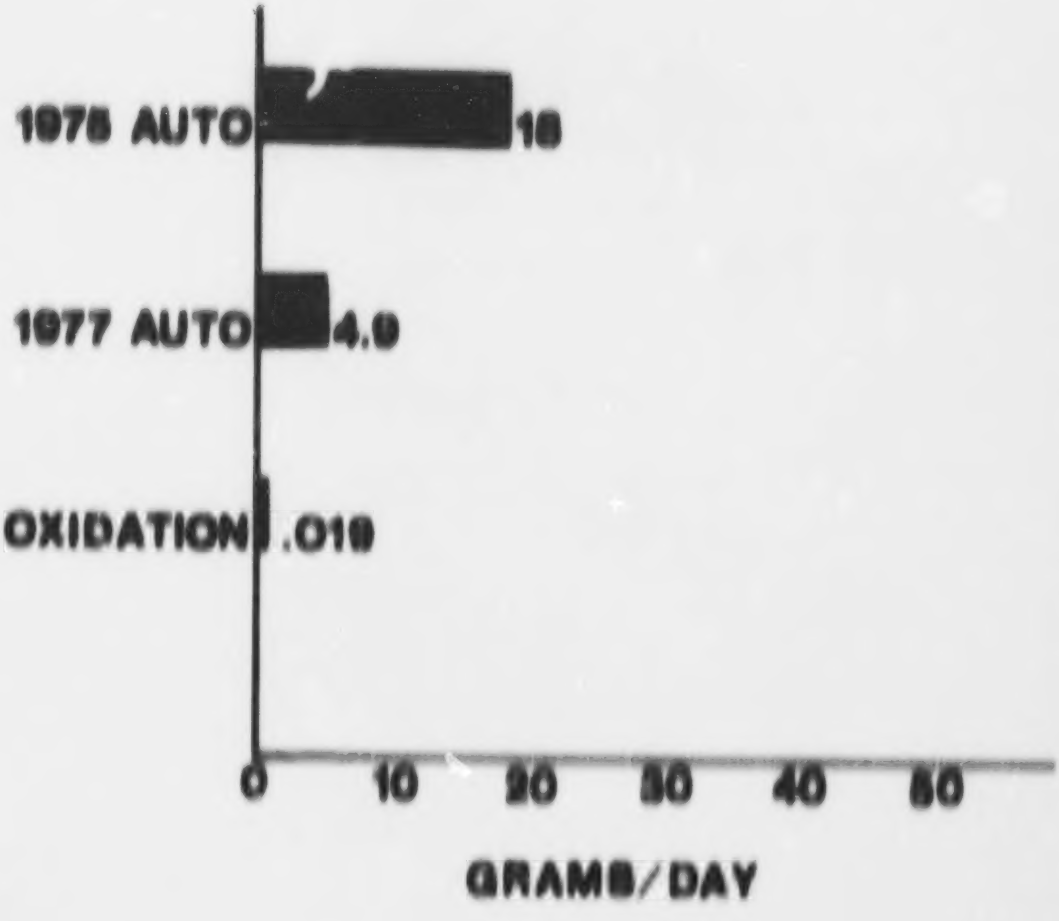
SLUDGE OXIDATION SYSTEM



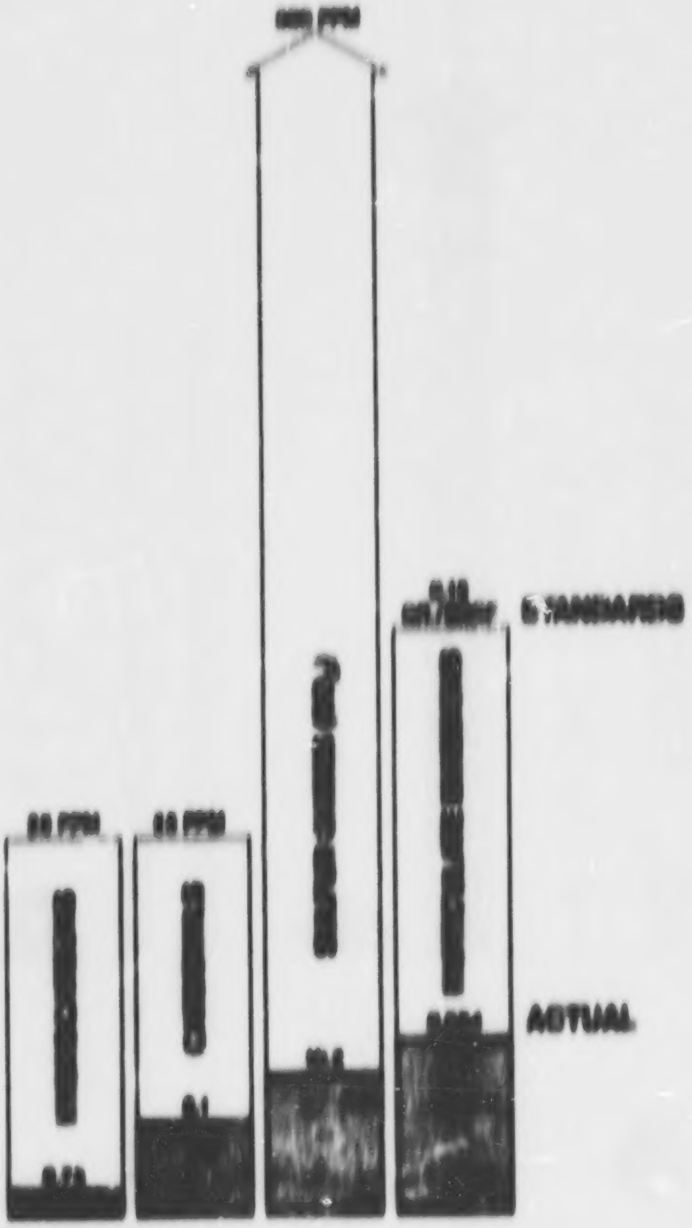
EXHAUST STACK
I.D. FAN
SCRUBBER
FURNACE
DRY ASH SYSTEM
BUCKET ELEVATOR
ASH BIN

TOTAL OXIDATION vs. AUTO

HYDROCARBONS



PALO ALTO EMISSIONS



NO$_x$ EMISSIONS

LIVERMORE VALLEY

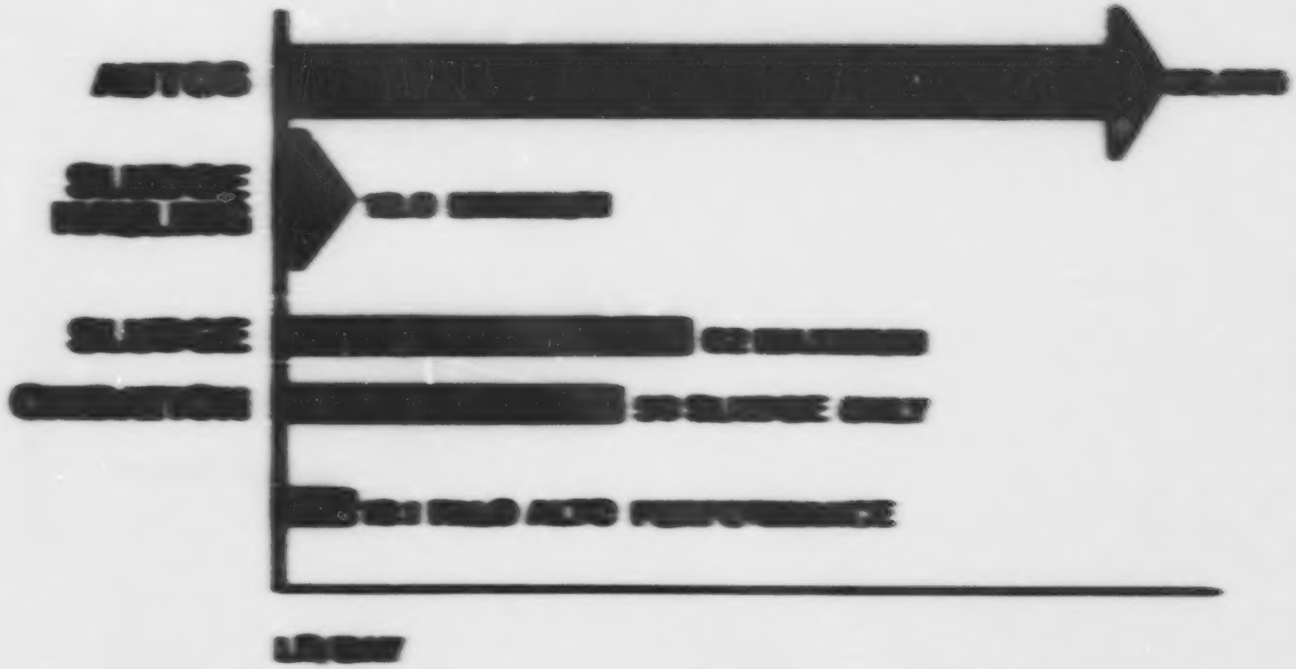
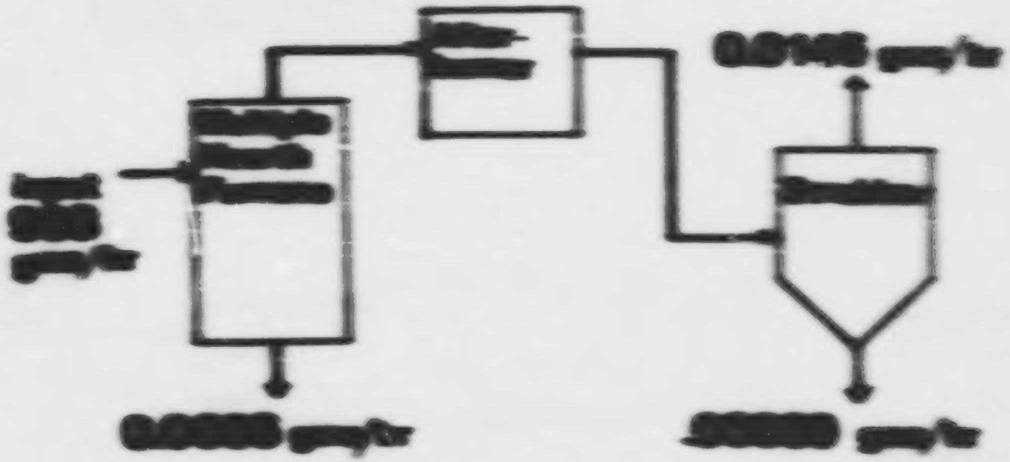


Exhibit: 5

DDT Removal in a Multiple Hearth Furnace

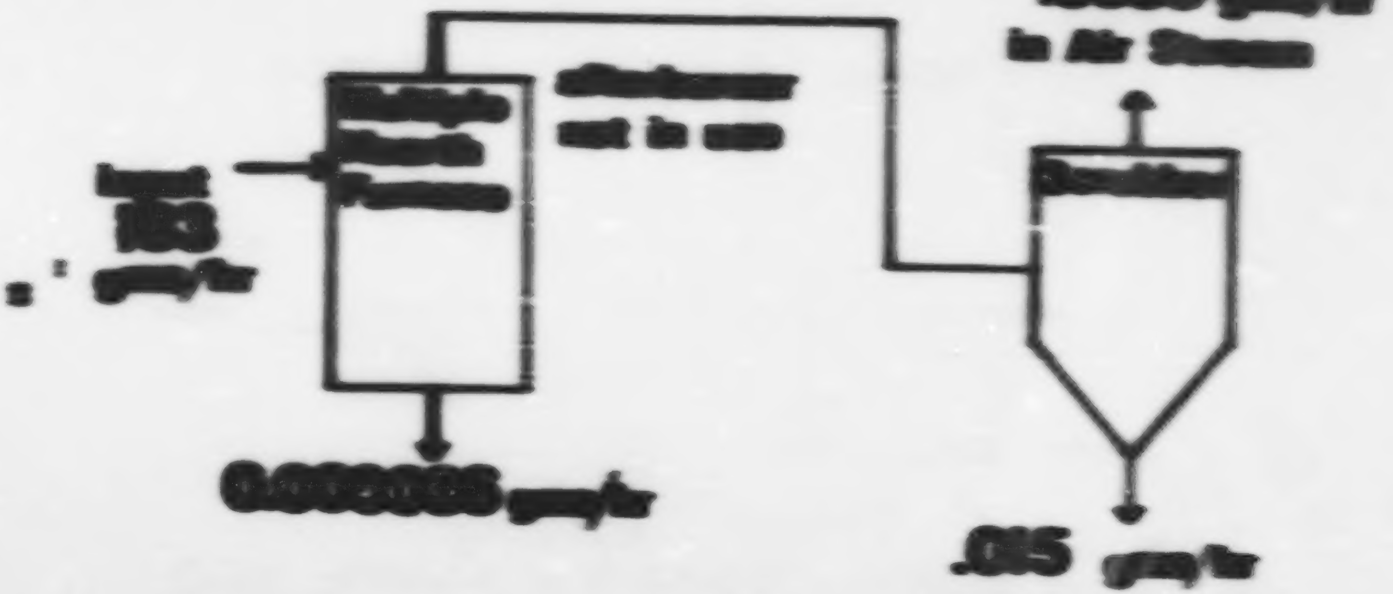


Input
[illegible]
gms/hr
Multiple
Hearth
Furnace
After-
burner
Scrubber
[illegible] gms/hr
[illegible] gms/hr
[illegible] gms/hr

Overall Removal Efficiency = ([illegible]) [illegible] = [illegible]%

Source—[illegible]/[illegible]

2,4,5-T Removal in a Multiple Hearth Furnace

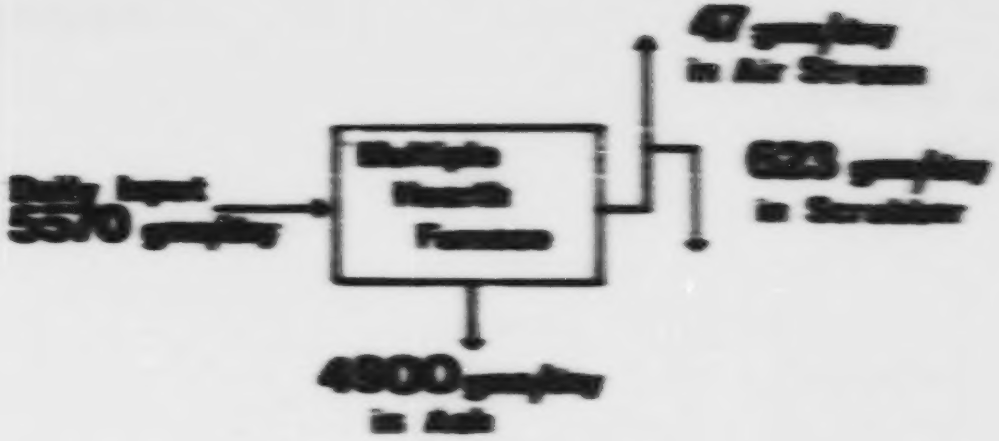

Input
153
gms/hr
Multiple
Hearth
Furnace
afterburner
not in use
Scrubber
[illegible] gms/hr
in Air Stream
.015 gms/hr
[illegible] gms/hr

Overall Removal Efficiency = $\left(\frac{153-[illegible]}{153}\right)$ [illegible]

Source-EPA/[illegible]

FIGURE 7

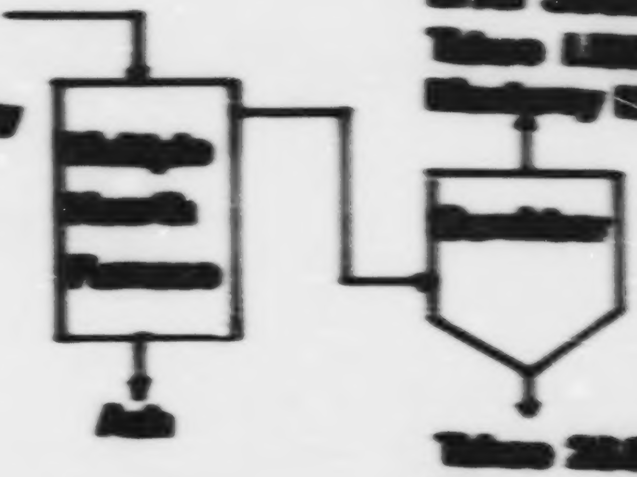
Lead Removal in a Multiple Hearth Furnace


Daily Input
5570 gms/day
Multiple
Hearth
Furnace
47 gms/day
in Air Stream
623 gms/day
in Scrubber
4900 gms/day
in Ash

$$\text{Scrubber Removal Efficiency} = \left(\frac{623}{623+47}\right)100 = 92.98\%$$

source: EPA/Tanner

MERCURY REMOVAL IN A MULTIPLE HEARTH FURNACE


Multiple
Hearth
Furnace
Ash
Scrubber

Daily Input
Toluene [illegible] g/day
Mercury [illegible] g/day

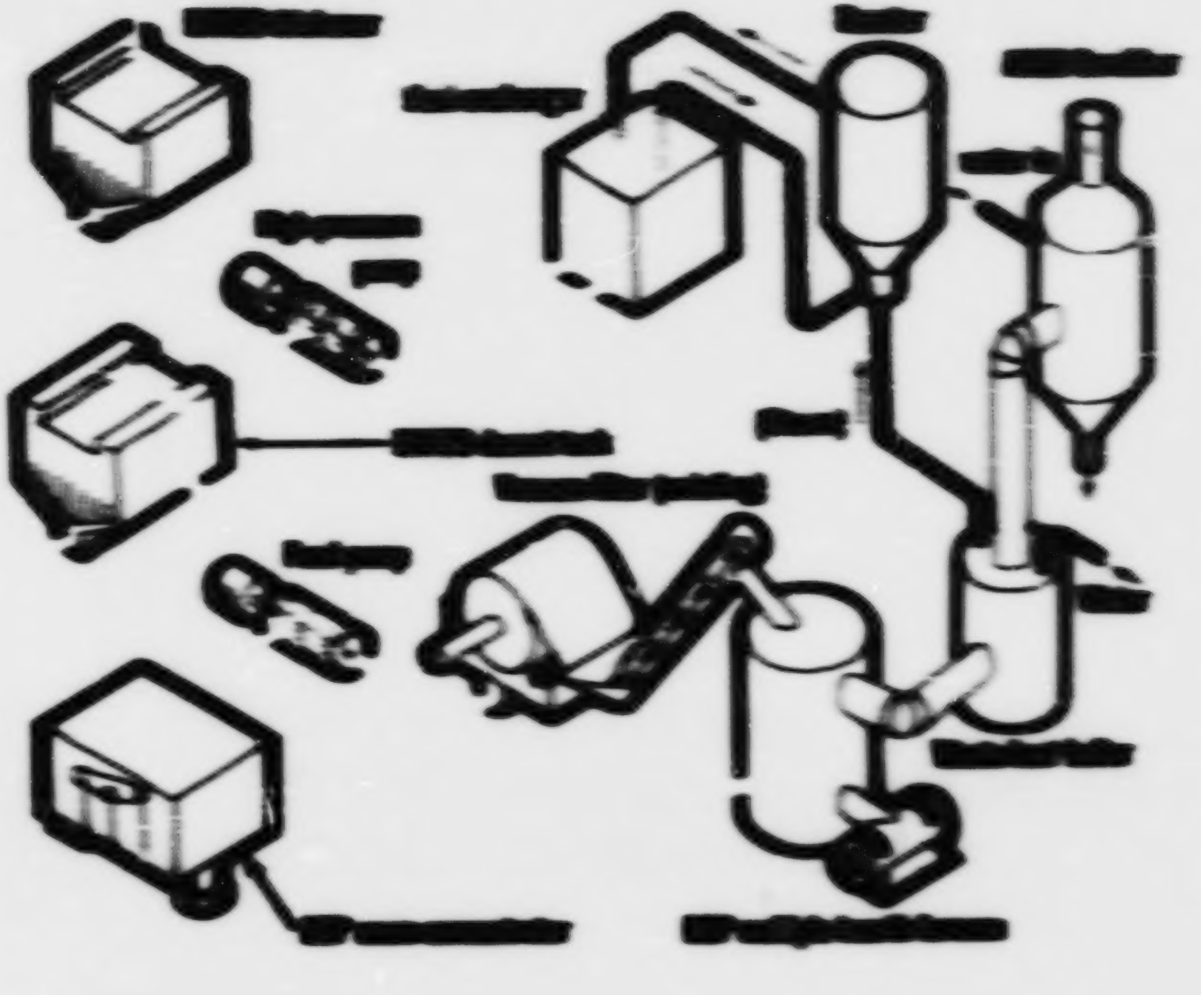
In Air Stream
Toluene [illegible] g/day
Mercury [illegible] g/day

Toluene [illegible] g/day
Mercury [illegible] g/day

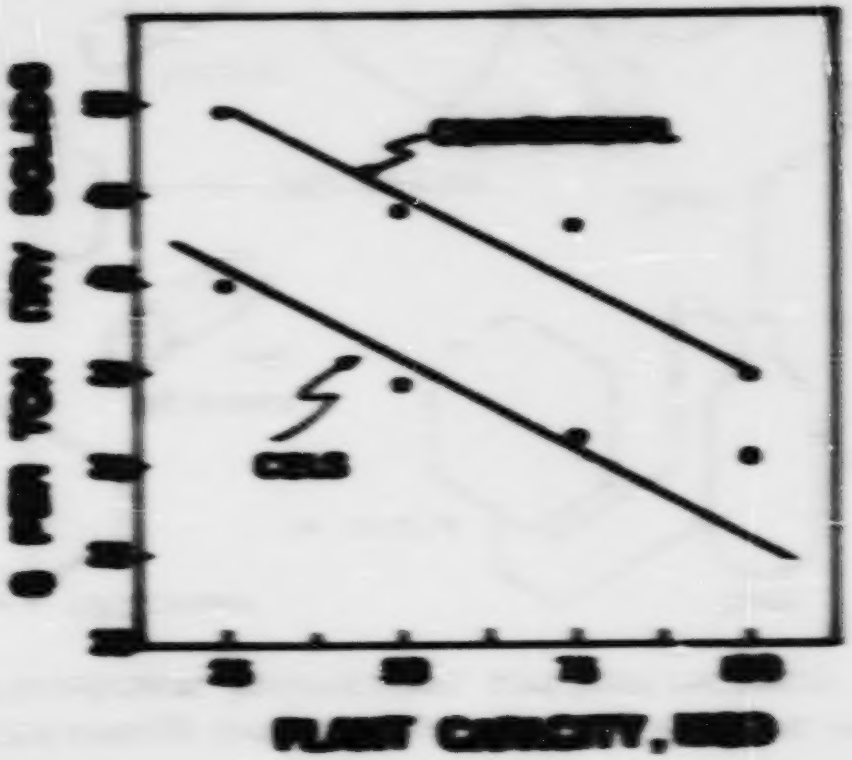
Scrubber
Removal
Efficiency : Toluene ([illegible]) [illegible] = [illegible] %

Mercury ([illegible]) [illegible] = [illegible] %

Closed energy loop, sludge handling systems incorporating heat treatment, incineration, and heat recovery



COST COMPARISON OF CLOSED ENERGY LOOP SYSTEM vs CONVENTIONAL SYSTEM



MANAGEMENT OF OIL SLUDGE FROM A REFINERY WASTE WATER TREATMENT PLANT

by [illegible]
[illegible]

Bashkirian Scientific Research Institute
of Petroleum Refining
(USSR)

SUMMARY

Oil sludge sources at refineries, its quality and petroleum contents are discussed. Operating data for oil sludge incineration in fluid bed incinerators, rotary drum kilns, and incinerators equipped with atomizing burners are presented. Incinerators of different design are compared. Various approaches to improve incinerator capacity by the reconstruction of main assemblies as well as operating data for incinerators equipped with rotary burners are presented.

Refinery and petrochemical waste water treatment plants give rise to a significant quantity of oil sludge whose disposal problem has not been yet solved. Some refineries [illegible] storage of sludge.

Oil sludge is largely formed by solids entering industrial sewage with make-up water, as a result of equipment cleaning and the plant site cleaning, with storm run-off as well as by dust blown in from air to the cooling towers, and biological growths in recirculating cooling systems. Oil sludge is also produced in storage tanks both for crude and commercial, finished oil.

The above suspensions entering the refinery sewer system and moving along the conduits become enlarged with petroleum products and while settling out in the [illegible] treatment form oil sludge which contains up to [illegible] to [illegible]% of solids and up to [illegible]% of petroleum products.

[illegible] methods for oil sludge discharge and [illegible] from the treatment facilities lead to highly water-bearing the oil sludge entering a gathering pond, petroleum products and solids content being as low as 1 to [illegible]%. As the oil sludge accumulates in gathering ponds, a partial separation of petroleum products and water takes place. The separated petroleum product after proper treatment is used in the refinery for reuse, the water free from settled solids being fed to the primary waste water treatment unit.

The oil sludge consists of several layers. Upper layers contain from [illegible] to [illegible]% of petroleum products and [illegible] to [illegible]% of solids while lower layers contain as low as [illegible] to [illegible]% of petroleum products and as high as [illegible] to [illegible]% of solids.

In recent years, many refineries and petrochemical plants have put into operation biological treatment facilities producing waste activated sludge in amounts as high as [illegible] m³ per 1000 m³ of influent waste water, with water content of 97 to 99%, which contributes to total refinery wastes.

A study of different methods of oil sludge utilization (oil stripping, thickener usage, various solvent extraction, etc.) has revealed their incapability of providing complete petroleum product separation, petroleum product content in residual solids being [illegible] to [illegible]%, their dumping is not feasible. Oil sludge management by burning rather than utilization has proved to be the most efficient and reliable means providing for practically complete oil sludge disposal, ash of no harmful effect being a result of the incineration.

In the Soviet Union, the following methods for oil sludge incineration have been tested on pilot and large scale:

1) rotary drum kiln incineration;
2) incineration in a furnace with bubble burners;
3) incineration in a fluid bed of heat carrier;
4) incineration in a furnace with atomizing burners.

Studies of rotary drum kiln incineration performed in our country on a pilot scale have shown the combustion to be incomplete, about [illegible]% of non-burned substances being carried away with off-gases in spite of a two- or three-fold air excess.

One of USSR refineries is operating an oil sludge incinerator with a rotary drum kiln (Fig. 1).

This kiln is intended for the incineration of oil sludge containing [illegible] to [illegible]% of solids at a temperature of about [illegible]°C.

The Soviet Union has gained a large-scale experience in incinerating the oil sludge in furnaces with bubble burners, the system is simple. The oil sludge is pumped from a gathering pond to a [illegible] where it is heated, [illegible] from where then pumped into the kiln. Incinerators with bubble burners are capable of incinerating [illegible] and oil sludge containing major quantities of solids (up to [illegible]%) and at least [illegible] to [illegible]% of petroleum products, the [illegible] m diameter and [illegible] m high kiln capacity being [illegible] to [illegible] [illegible] (Fig. [illegible]). The incinerators

subsequent increase in the lining life up to 17 to 18 months.

Cooling off-gases is a combined procedure. The off-gases are cooled by water injection in the furnace and scrubber, then in the air cooler made of ribbed cast iron tubes, the off-gases with dust blown in being passed through the intertubular space and the cooling atmospheric air through the tubular space. To clean the ribbed tube surface from ash deposits, a shot blasting device has been mounted providing for a complete cleaning of the cooler dusty surfaces by cast iron shot. The device is switched on once per shift for some minutes.

The inclusion of the above and other improvements in the unit scheme has made it possible to reach an average capacity of 2.7 tons/hr, a maximum capacity of 4 tons/hr being achievable when burning the sludge containing 35 to 47% of petroleum products, 5 to 10% of solids.

Operating the unit makes it possible to dispose of all the oil sludge produced, which contributes to a considerable improvement of the waste water treatment effect for the refinery treatment facilities.

The flow diagram of the most promising oil sludge incinerator is shown on Fig. 6.

The oil sludge from treatment facilities goes to a pretreatment tank where it is freed from water excess and petroleum products and is then fed to a storage regulator. The oil sludge heated to 80 to 90°C goes from the storage regulator to a rotary burner and is burned in a fire box of the incinerator. The off-gases leaving the incinerator are cooled by water injection, freed from dust in a set of cyclones and discharged into the atmosphere. The ash trapped in a cyclone accumulates in a bunker and is dumped periodically. The above scheme makes it possible to most economically incinerate the oil sludge.

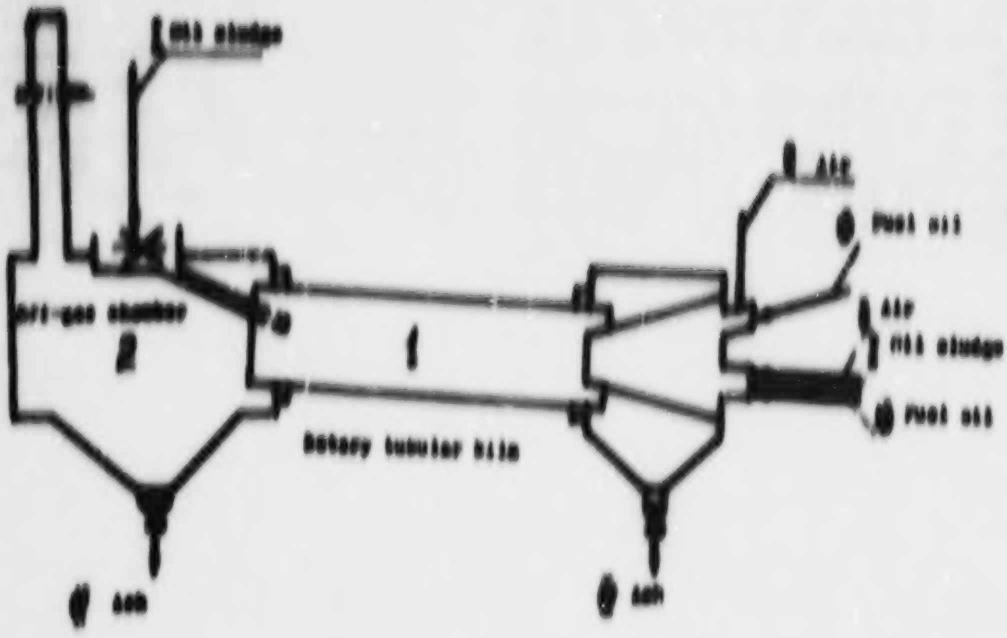

I oil sludge
off-gas
off-gas chamber
2
1
II Air
III Fuel oil
II Air
I oil sludge
III Fuel oil
Rotary tubular kiln
IV ash
IV ash

Fig.1. Rotary drum kiln

1 - rotary tubular kiln

2 - off-gas chamber

Streams: I-oil sludge;II-air;III-fuel oil;IV-ash

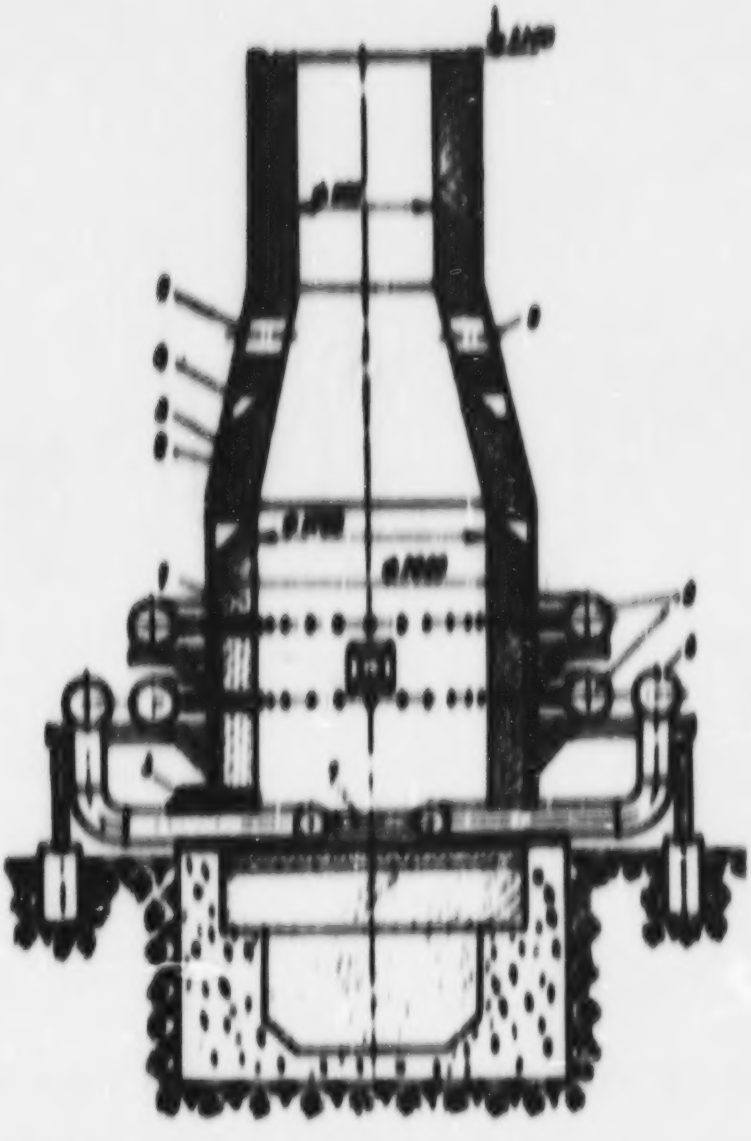


Fig.2.Kiln with bubble burner

1-housing;2-fireproof lining;3-heat insulation;
4-supporting belt;5-feeding pipeline;6-primary air;
7-bubble grate;8-secondary air;9-orifices for the suction of atmospheric air

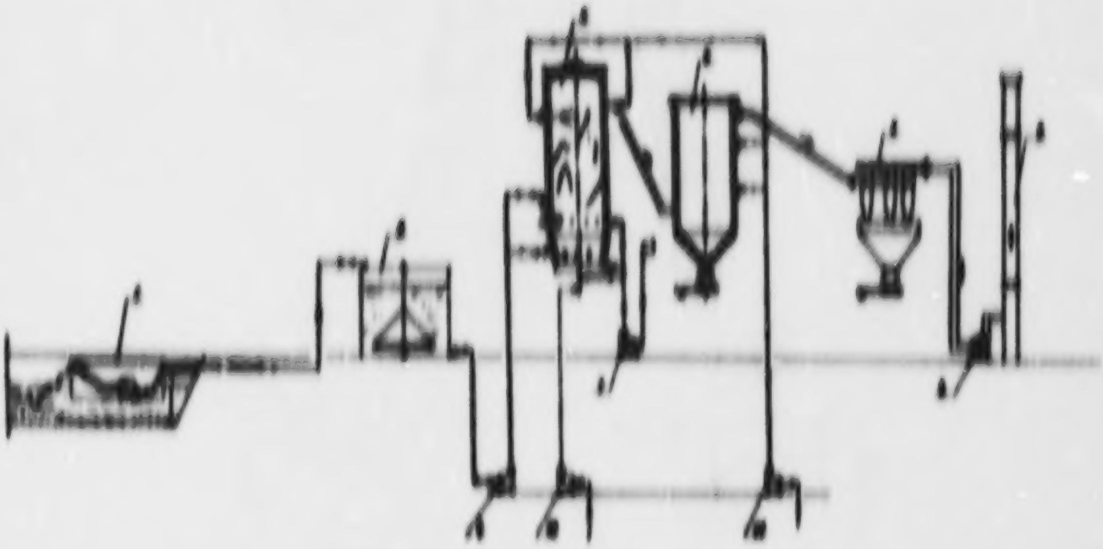


Fig.3. Oil sludge incineration in a fluid bed

1-floating pump assembly;2-sewage regulator;3-vertical kiln; D=3,6m,H=8,5m;4-scrubber of VTI type;5-battery cyclone;6-stack; 7-air blower;8-flue gas blower;9-sludge pump;10-fuel pump; 11-water for cooling

Fig.4. General view of rotary burner

Fig.5. General view of oil sludge incinerator

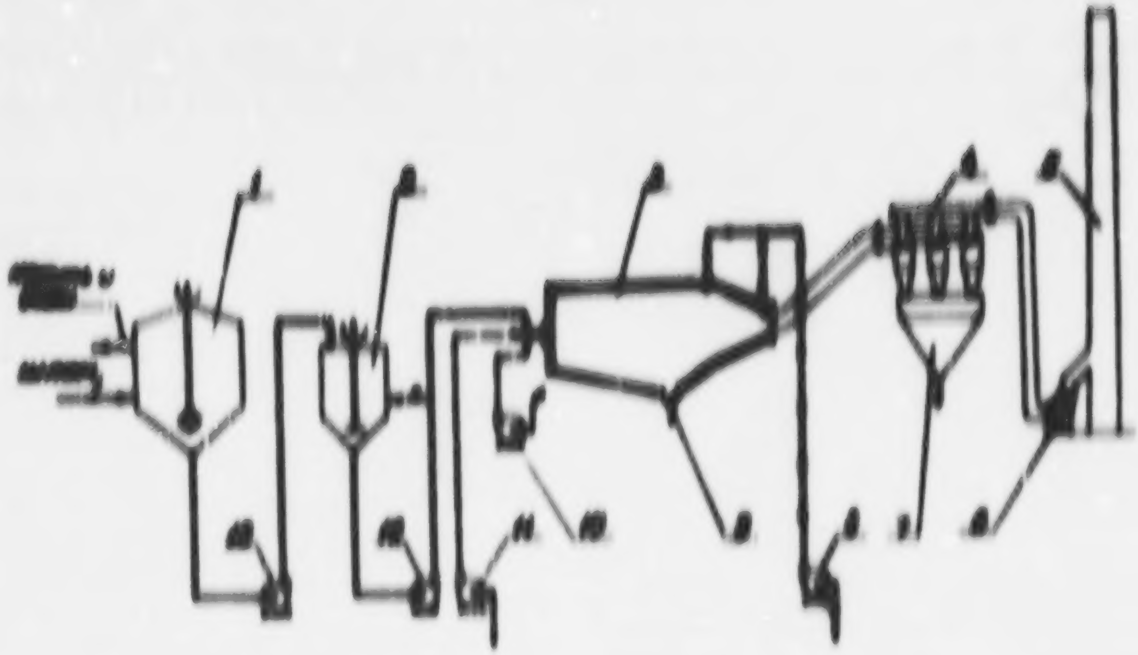


Fig.6. Flow diagram of the most promising oil sludge incinerator

1-oil sludge pretreatment tank;2-sewage regulator;3-furnace with a rotary burner;4-a set of cyclones;5-stack;6-flue gas blower;7-bunker for ashin-water supply;9-slag removal;10-air blower;11-fuel supply;12-sludge supply;13-sludge supply

[illegible]

by [illegible], All-Union [illegible] Research Institute [illegible]

[illegible]

[illegible] depends on sludge physical and chemical properties and on local conditions for treatment plant construction. Therefore the choice of a rational technological treatment scheme is a complex engineering economic problem the solution of which in many cases requires the performance of the experimental researches in some variants.

The important scientific and practical problems in [illegible] wastewater sludge treatment are to give objective evaluation to currently used methods and equipment, to establish the range of its rational use, to find out the most promising trends in further scientific research and test design works and to coordinate activities in this field.

[illegible]

It is known that the increase of sludge thickening intensity provides large opportunity for simplifying of the technological treatment scheme. At current trend of using the heat methods (drying or incineration) in the last stage of sludge treatment the increase of thickening intensity enables to refuse from such expensive stages as conditioning and mechanical dewatering namely the whole technological process is represented by two stages as thickening drying (for [illegible] sludges) and thickening and incineration (for not [illegible] sludges).

Therefore over the past years we study such processes as flotation, centrifugal separation and vibrothickening. The extent of studies' improvement is various.

In regard to flotation thickening the research is carried out in pilot and full scale and the process for activated sludge thickening is in process of being introduced at many enterprises of our country. With this method the solids concentration achieves up to 7% and the treatment time can be reduced by 3-4 times versus the gravity thickening.

As concerns the centrifugal thickening of activated and other sludges the studies are now carrying out and are aimed at the choice of more rational constructions for disk type centrifugal separators.

[illegible]

[illegible] is an alternative to anaerobic digestion.

Aerobic stabilization advantages are the large process stability, the ease of operating and the lower plant construction costs.

The aerobic stabilization process has recently been put into practice at many biological treatment plants of low and average capacities. The stabilization period for activated sludges of various wastewater types is on the average in the 8 to 11 day range. Stabilization of 1 kg of activated sludge organic matter requires about 0.7 kg of oxygen. The increased energy expenditures on aeration refer to disadvantages of the aerobic stabilization method. Under the same conditions the aerobic stabilization process is estimated to be more advantageous than digestion for the plant capacities up to 100 000 m³/day. However the method can be employed at larger plants if digestion process has no utilization for outlined above reasons.

In our country only the reagent method is so far used for sludge conditioning prior to the mechanical dewatering. Ferric chloride and lime are predominantly used as reagents. The reagent consumption is very considerable and treatment cost amounts up to 60% of total expenditures spent on sludge dewatering.

Heat treatment (Porteous process) is considered to be an advanced sludge conditioning method among promising others. Based on the laboratory tests and [illegible]

[illegible]

In our country sludge conditioning by using high molecular polyelectrolytes (flocculants) has not yet employed in full scale. The present studies are aimed to find out and develop the most promising and effective types of flocculants additives. In the USSR three main processes of vacuum filtration, pressure filtration and centrifuging are commonly used for wastewater sludge mechanical dewatering. Vacuum filtration is now the most developed and improved process used in many towns and at industrial enterprises of our country. The object of research and design works currently performed in this field is to improve and modernize the vacuum filter construction, to intensify the process and to determine experimentally proper technological parameters for the particular kinds of every wastewater sludges.

In our country pressure filtration for wastewater sludge dewatering has been recently used. In the USSR the automatic compartment pressure filters of type FPAKM are now manufactured that proved to be suitable for dewatering of many kinds of wastewater sludges. The filter pressing enables the greater extent of sludge dewatering to be accomplished versus vacuum filtration and centrifuging. So in the case of sludge treatment of municipal sewage the cake water content is achieved in the range of 60% [illegible] the efficiency by sludge dry weight is about 15 kg/m²/h. However as concerns the filter pressing efficiency, as a rule it is generally yielded to vacuum filtration and centrifuging. Therefore the filter presses are advisable in cases where the last treatment stage of sludges requires the use of heat drying or incineration.

In our country the centrifugal method for sludge dewatering is not yet extensively used. However the evident advantages (compactness, good sanitary conditions, ease in operating, wide range for control of process variables) place this method to be considered as an advanced one. The solid-bowl centrifuge development of a particular type with a capacity up to 10 m³/h is being carried out, allowing this effective method for dewatering to be more widely used in the future.

Vibrofiltration is one of the new methods for wastewater dewatering. The process attracts attention by its high efficiency and comparatively low capital and operating expenditures.

Tests performed on the laboratory vibrofilter model for municipal wastewater sludge dewatering gave the following results:

- efficiency is in the range of 100-140 kg/m²h
- cake water content is about of 80%
- degree of solids capture with filtrate is of 95-98% (the sludge is digested under thermophilic conditions and is treated by ferric chloride and by lime).

The pilot vibrofilter is now developed and the experimental works will be continued by using it.

Sometimes the heat drying is required in the last treatment stage if the wastewater sludges have utilization as agricultural manure.

This process provides also the sludge disinfection in addition to extra wastewater decrease.

The drum kilns for heat drying of the dewatered sludges are used at two treatment plants of Moscow municipal sewerage system.

The new technical approach to this process is the use of dryers with gas counter current that reduces the capital expenditures by 3-4 times and the operating costs by 15% versus the drum dryers. Based on this principle two experimental lines have been constructed. The first is for the heat drying of wastewater sludges in [illegible], the other unit is for the drying of lignin sludge at a cellulose plant.

Incineration is recognized as one of the most radical methods for disposal of unutilized organic sludges.

In the USSR certain experience is available in incineration of process liquor sludges produced at wastewater treatment of the petroleum refinery plants. The incineration of dewatered sludges has not used up to now. However in the very near future it will be [illegible] used for subsequent experiments at using of different kinds of sludges.

Summarizing all the outlined above, the main problems that are brought forward before our scientific research and design institutes and industrial enterprises in the field of wastewater sludge treatment can be classified into the following groups:

1. Development and improvement of complicated devices and apparatus manufacturing for sludge heat treatment including:
   a) heat treatment for sludge conditioning prior to dewatering,
   b) heat drying of dewatered sludges for its utilization in agriculture,
   c) incineration of unutilized sludges to reduce its mass.
2. Development and improvement of equipment and plant constructions for sludge vibrothickening and dewatering.
3. Development and improvement of efficient flocculation additives production for sludge conditioning.
4. Development and improvement of modernized centrifugal separators for sludge thickening and dewatering.
5. Carrying out the complex investigations on agricultural and sanitary-hygienic evaluation of wastewater sludges.

MANAGEMENT AND DISPOSAL OF RESIDUALS FROM TREATMENT OF INDUSTRIAL WASTEWATERS*

by

William J. Lacy and Allen Cywin**

INTRODUCTION

The Water Pollution Control Act and Amendments of 1972 and the Clean Air Act require industry to treat their liquid and gaseous wastes in accordance with best treatment practices.

The subject of this paper is similar to the topic of a recent (Feb. 3-5, 1975) Conference namely "National Conference on Management and Disposal of Residues from the Treatment of Industrial Wastewaters." The proceedings have been published and are part of the eleven reports (list attached) we are submitting to you.

It is our intention to present a summation of what the speakers actually said.

Mr. Roger Strelow, Assistant Administrator, Air and Waste Management, U.S. Environmental Protection Agency, indicated industrial residues are expected to double in the next 10 years. Some will consist of toxic residues, which if improperly disposed on the land can cause harmful effects from leaching, sublimination, evaporation, runoff, or direct contact.

Hazardous waste residue regulations are currently lacking. Public pressure for legislation has been limited probably because the problems are not quite understood and/or solution may be out of sight.

However, the Office of Solid Wastes Management Program is preparing guidelines for acceptable storage, treatment and disposal of residues which are imminently hazardous.

EPA is urging process improvements to reduce the amount of residues generated by industry.

The method is by reducing pollution in the environment and the cost of treatment by recovery of resources for reuse by the industry or by others as a means to conserve energy.

Mr. George Rey, EPA's Industrial Pollution Control Division presented a detailed technical analysis of industrial residue disposal and an overview of the EPA R&D effort. The intermedia transfer of pollutants was under study by the Federal Water Pollution Control Administration in 1966 and was the forerunner of current EPA efforts.

Open cycle and closed cycle systems with total environmental control were discussed.

EPA's program is viewed as an integrated effort of industrial wastewater treatment, and water reuse, residue reuse, and disposal.

A residue management check list for industry was presented.

"Zero discharge" as an economically viable goal may be achievable when we consider water reuse and resource recovery.

Mr. John P. Lehman, Office for Solid Waste Management Programs indicated that residue disposal is of international concern with U.S. lagging behind a number of countries. He presented amounts of residues from various sources i.e. industrial waste residues of 260 million dry tons/year which is twice the amount of municipal solid wastes and 30 times that of municipal sewage solids.

Moreover between 1971 and 1983, industrial residues from pollution control are expected to double these quantities.

At least 10 million dry tons/year of residues may be toxic. 40% of residues are inorganic and 10% are liquid.

Although technology is available there is no economic or legislative requirements to solve problems. Proper disposal techniques may cost $40/ton.

Residue disposal with exception of pesticides and radioactivity is not subject to current Federal regulations.

A strong Federal regulatory program is needed which will deal with the residue problems from "cradle to grave."

Mr. Murray Newton, presented a discussion of State standards and programs for hazardous residues disposal. Much of the Federal activity on hazardous wastes management has occured during the last year.

Minnesota, California, and Oregon, have comprehensive hazardous wastes management programs which control "life cycle" of residues. Most other states have programs which have discrepancies because they are not comprehensive.

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*Presentation at the U.S./USSR "Handling Treatment and Disposal of Sludges and Industrial Residues" Symposium Moscow, USSR, May 7-8, 1975.

**Respectively, Directors of the Industrial Pollution Control Division, R&D and Effluent Guidelines Development Division, U.S. EPA, Washington, D.C.

EPA's Office of Solid Waste can currently provide some financial and technical assistance to states to develop hazardous waste management programs.

Current problems in similar disposal programs are:

1. Administration of programs
2. Concentration of problems in a limited number of states
3. Free movement of residues is prohibited
4. Lack of data base

We can expect increased activity in legislation and programs.

However, with or without Federal legislation, the States must move ahead and not wait for the political action.

Mr. John Monteith of the Canadian EPA pointed out very clearly that environmental policy in Canada is influenced by the factors of geography and climate and the complexity of governing bodies. Also, discussed was the degree of responsibility assumed by each of these bodies: total, shared or limited.

Legislation on the Federal level is in the formative stage. It includes the proposed Environmental Contaminants Act and the Ocean Dumping Act. Research programs under the Canada/Ontario agreement for Great Lakes Water Quality include waste characterization and sampling methodology. Land disposal of sludges cover heavy metals and persistent organics.

Mr. Lawrence D. Kramer, Minnesota Pollution Control Agency stated the ability to control solids disposal on land sites involves learning where such sites have been located, and to establish requirements for each site. That includes operation, an adequate system of monitoring, and reporting the results. Consideration is being given to establishing regional plants for detoxifying sludges before land disposal.

Dr. Thomas Short, EPA reported that a survey of industrial solids disposals as well as liquid concentrates in Ventura County indicates the need for a centralized treatment plant to accept all industrial waste concentrates. A survey quantifying the volume and quality of these wastes indicates the variability is such it is not practical to handle such wastes in existing municipal wastewater treatment plants. Solids now sent to landfill sites may be diverted to this centralized treatment facility. Joint industrial-municipal studies are underway to evaluate the detoxification of all wastes for land application of organics and for ocean disposal of inorganics.

Ms. Martha Gordon, Development Sciences Inc. presented an excellent description of an EPA sponsored project on the history of traditional in-plant management of contaminating problems which [illegible] effective [illegible] of each. The five case histories [illegible] impact of industrial [illegible] of public and private [illegible] treatment and recovery of mercury, chloro-alkali, organic solvents, and nickel metal bearing wastes.

Mr. Samuel Morekas, EPA presented an assessment of hazardous waste practices in several industries. He pointed out that potential hazardous wastes are increasing at a rate of 5-10%/yr. His offices currently have many industries under study. These studies include: inorganic chemicals industry, alkalies and chlorine, industrial gases, inorganic pigments, industrial inorganic chemicals. States are involved where the various categories of wastes predominantly occur. Also being developed are: Summary of treatment and disposal practices for various wastes and typical costs of selected wastes by various treatment or disposal methods.

In conclusion tentative indications are that land disposal methods in most cases do not provide adequate containment, nor is there sufficient monitoring of these wastes.

Mr. William T. Bush, Atlanta Water Bureau raised the question is a water plant a source of industrial waste effluents? Most would say NO. But because of the high turbidity in the water and Al $(OH)_3$ precipitate, the answer is YES.

Alum sludge treatment investigations were started in 1967, centrifuging, air flotation none of which didn't prove satisfactory. Following evaluation of unit operations the city of Atlanta engineers chose pressure filtration with diatomaceous earth precoat. They received bids in 1969, and started operating the plant in 1971.

Results: Plant operating at 1.5% solids which is then concentrated to 40% solids and pressed yielding 110 million gallons of H_2O and 8,071 tons of solids recovered from producing 13 billion gallons of water. The equipment used are the first two presses of their type in U.S. EPA provided 15% of funds required to this project.

He concluded that (1) Pressure filtration definitely works. (2) Water is returned to reuse. (3) Dewatered solids can easily be handled.

Mr. Kenneth Laird, Southwest Public Service Company stated that the Southwest Public Service Co. used: (1) Secondary treated sewage effluent for cooling. (2) They are able to treat water up to 5% solids. (3) The cooling tower blowdown was used for irrigation of [illegible] operations were: (1) Southern Public Service [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] and [illegible] [illegible]. (2) They used the [illegible] [illegible] [illegible] from the [illegible] [illegible] by [illegible] ("[illegible]") to [illegible] up the [illegible]. (3) [illegible] of [illegible] [illegible] to be produced by [illegible] [illegible] [illegible] and [illegible]. (4) [illegible] the [illegible] [illegible] [illegible] [illegible] by oil and [illegible] oil, and [illegible]. (5) They are also investigating use of [illegible] [illegible].

Mr. Leslie Pearce, Dravo Corporation gave a description of EPA data on power plants including scrubbing media utilizing both lime and/or limestone.

Thiosorbic process which uses lime with 3-6% Mg was described. He also described how the Calcilox® process works with an additive which is a waste product from the steel industry and is used to stabilize flue gas desulfurization sludge.

1 ton of 3% coal yields 1000 pounds of sludge, equal to 5% of weight of coal. By 1980, the industry will produce 100 10^6 tons (dry) of sludge annually.

He gave various potentially useful application for stabilized flue gas desulfurization sludge.

Mr. F. N. Davis, Utah Power and Light stated that a utility company (Utah P&L) is assessing the effectiveness of brine concentration as a technique for ultimately closing the wastewater cycle. Concentrated brines are rendered suitable for land disposal via natural evaporative dewatering mechanisms.

Dr. R. Willard, EPA is exploring two thermal systems (pyrolysis) to effect an economical disposition of bark residues from the pulp and paper industry. Potential economic advantages are associated with the conversion of the bark which can be converted into by products such as oil and that the related hot gas can be used in electricity generating gas turbines.

Mr. Jaquish, Barber-Coleman Corporation described wet oxidation, as a specific technology, which has been investigated relative to its usefulness in stabilizing spent ordinance (Military) materials. Pilot scale studies have documented the technical feasibility with costs acceptable to the Department of Defense.

Dr. Ronald D. Neufeld, University of Pittsburgh suggested that the normal biological sludge environment of a sewage treatment plant may in fact be the key in the scavenging of transition metals in industrial-municipal wastewaters. This type of information has a bearing on the degree of pretreatment that may ultimately be required for industrial discharges into municipal systems. The quantity and quality of sludges produced in this area related to pretreatment.

Mr. Howard [illegible], Manufacturing Chemists Association explained that several techniques involved are: [illegible], solids concentration by [illegible] [illegible], and separation by [illegible], and chemical [illegible].

In each instance the process has been scaled up by [illegible] and [illegible] [illegible] and [illegible] and [illegible] for economic evaluations and cost/environmental control effectiveness determinations.

It was significant that none of the papers presented at this session of the conference resulted in a waste material for disposal, the accent being on reuse or new use.

Dr. Craig Brandon, Clemson University paper was on the recovery of textile dye concentrates for reuse within the industry utilizing reverse osmosis techniques.

Mr. John W. Wade, Toledo Pickling and Steel Service dealt with the production of waste sludges from the pickle acid rinse water waste lines in a steel mill and with potential for by-product use as a concrete additive and/or fertilizer.

Dr. R. H. Cherry, Jr., Battelle-Columbus Laboratories reported on an EPA sponsored project. General purpose of work was to develop a technique for recovering the metals spent electroplating baths and rinse waters. Recycle waters to rinse operations also detoxify existing sludge stores.

Seven platers installations were visited to gain background in sludge sources and production technology and to review waste treatment techniques.

Mr. Peter L. Horn, The New Jersey Zinc Company discussed TiO_2 production which produces a waste H_2SO_4 waste stream containing metallic sulfates.

A process was developed with EPA's help to reclaim sulfuric acid. Concentrated sulfuric acid from this waste and a 3 Ton/day pilot setup has been successfully handled.

A spray drier evaporates water and produce H_2SO_4 to get a dry metal laden solid. This material is quite soluble which if not reused makes disposal a significant problem.

Vapors are condensed in multiple stages to give concentrate sulfuric acid (93%).

The process loses a small amount of acid as mist and SO_3.

New Jersey Zinc Company has designed 345,000 metric ton/yr. commercial plant to process waste H_2SO_4

at a total cost of $1,250,000 or $11/T (metric) solid [illegible].

Fuel demands and residuals remain serious problems to be solved.

Dr. J. T. Lawhon, Texas A&M University discussed treating cottonseed whey from protein isolation from cottonseed flour by ultrafiltration and reverse osmosis. The process produces [illegible] of the [illegible] as a solid waste product.

Ultrafiltration membranes are utilized to retain proteins, and passed most of remainder for additional treatment.

A second new protein whey fraction was recovered by the reverse osmosis membrane.

Spray dried protein concentrates from the UF membrane were used as protein fortifiers in breads, non-carbonated beverages, and as whipping/dessert products.

Dr. Sheldon Bernstein, Amber Laboratories, reported that saccharomyces fragilis are easily grown on cold or sweet whey continuously in an aerated fermentor-cell [illegible] several [illegible] as a high grade protein food material.

Sterility is not a problem due to low pH. Lactose is carbohydrate substrate.

Ethyl alcohol can be produced and recovered with lower cell yield.

Using centrifugation, food grade yeast can be produced. However, the supernatant streams does create a disposal problem.

Protein quality appears to be good. They whey is low in sulfur amino acids. No toxicity was exhibited in rat feeding.

Dr. Richard L. Olson, Resources Conservation Company presented a unique dewatering system using an aliphatic amine capable of processing a wide variety of municipal and industrial sludges is being developed by his company.

This system, Basic Extracting Sludge Treatment (B.E.S.T.) has had extensive laboratory evaluation during past two years.

System prototype tests are currently being conducted. B.E.S.T. appears capable of handling large number of organic and inorganic sludges. Results vary depending upon sludge type. Good results obtained with municipal sludges. Pulp and paper sludges were also tested with similar success.

Variable results were obtained with steel industry sludges.

Dr. H. Rebhan, Farbwerke-Hoechst-Uhde Corporation reported on a new process developed by Hoechst [illegible] hydrocarbons and their chlorinated [illegible] [illegible] by [illegible] [illegible] [illegible]. [illegible] and [illegible] [illegible] [illegible]. The process recovers the carbon value of the [illegible]. It is a completely closed recycle system. A semi-commercial plant producing 8,000 mt/yr. [illegible] operating since 1976.

A commercial plant (50,000 mt/year) is under construction. Another plant (10,000 mt/year) is being planned for the U.S.S.R.

Mr. [illegible] J. Gallay, Imperial Holding AG in his paper described the design of incineration burners. These burners are used on ships which incinerate chemical waste. It was claimed that the cost of incinerating many hazardous wastewaters is lower than treatment. Consequently, many manufacturers prefer thermal disposal.

These ships were originally designed to incinerate liquid chlorinated hydrocarbons. However, their modification burners have permitted the burning of high water content waste.

Some plants generate large volumes of chemically contaminated water. Thermal disposal of such large volumes is too expensive. Volume reduction is necessary. However, this involves an increase in sodium concentration of the waste which results in strong corrosion of the lining of the combustion chamber. Work is under way to attempt to solve this problem.

A third incineration ship will be commissioned at the end of 1978. This ship will have a furnace capable of incinerating both liquids and sludges.

Wastes would not be incinerated unless approval was received from the regulatory agencies of the countries of origin.

Dr. A. Sadana, Enviroengineering, Inc. indicates that two new refinements of the Carver-Greenfield multi-effect evaporator process have been successfully used to treat/reduce wastes residues from a pharmaceutical processing operation and a pet food plant. The first refinement is the inclusion of a pyrolyzation step which decomposes the organic material in the dried solids (pharmaceutical wastes) into volatile hydrocarbons to be fed to the boiler burner as fuel, thus promoting energy recovery and resulting in a minimum amount of ash. The second refinement is the drying of dilute and concentrated pet food waste stream simultaneously and recovering by-product fit for resale. Both refinements to the multi-evaporator process close the "systems loop" and approach zero discharge. The technical aspects and economics of implementing the two refinements of the [illegible] process to the two waste streams were discussed.

Mr. [illegible], [illegible], Inc., described a [illegible] process for [illegible] of [illegible] to [illegible] "[illegible]" with regard to "[illegible] Organic."

Mr. Robert A. [illegible], Chem-Trol Company described a [illegible] approach to handling sludge from [illegible] chemical [illegible] industry. [illegible] [illegible] is to recover substances of value from the sludge.

Mr. Robert Landreth, EPA presented discussion of chemical fixation of hazardous, [illegible] wastes particularly those from sulfur oxide scrubbers prior to land application.

Mr. Donald [illegible], President of the [illegible] Foundation presented the background and a description of events leading to a demonstration of the destruction of hazardous substances by incineration at sea. The presentation was formally discussed by a representative of the Environmental Protection Agency.

The EPA scientist indicated that the permit issued for actual burning was for a one time operation and did not amount to an endorsement of this technique.

Mr. Alfred Lindsey, EPA reported conventional sanitary landfill of hazardous or potentially hazardous waste can lead to the contamination of surface or groundwater due to leachate and runoff problems, particularly in areas where the annual precipitation rate exceeds the evapotranspiration rate. Methods were proposed to modify the conventional sanitary landfill to ensure proper disposal of chemical and hazardous industrial wastes.

The paper examined some of the techniques currently available to prevent, collect, treat, monitor, and manage chemical waste landfill leachates. In addition, hazardous waste preparation techniques, employed to minimize waste hazardous prior to secure landfill disposal, were presented.

Mr. Edwin P. [illegible], Union Carbide Corporation, reported that waste activated sludge from its own industrial waste treatment unit is used by this moderate-sized, agricultural chemical plant to [illegible] its [illegible] [illegible] with [illegible] the plant's [illegible].

The [illegible] "[illegible]" [illegible] of the chemical [illegible] is [illegible] and [illegible] to the waste treatment unit for [illegible].

Final [illegible] of the sludge [illegible] [illegible] [illegible] 1977 federal effluent guidelines.

In [illegible], the treatment unit, the [illegible], and the special chemical landfill provide a low energy, closed, [illegible] disposal cycle for the [illegible].

Mr. George B. [illegible], Mallinckrodt, Inc., reported [illegible] with the development of a land application system for an industrial waste water high in nitrogen content. The land application is an integral part of the waste water treatment system.

Mallinckrodt, Inc., operates a synthetic organic chemical manufacturing plant north of Raleigh, N.C. The products from which the waste water is obtained are organic pharmaceutical and medicinal chemicals. The overall treatment system consists of in-plant neutralization, equalization, an anaerobic lagoon, two aerated basins in series, clarification and sludge recycle, and land application by spray irrigation. The spray irrigation of the treatment plant effluent together with wasting sludge is proposed and is not yet included. Because of severe limitation of discharges to the local Neuse River, land application is the only system found to be technically feasible for the disposal of the final effluent.

In summation Dr. Lazar, EPA indicated that the hazardous waste disposal problem has assumed particularly significant proportions because of the progressive implementation of air and water pollution control programs, ocean dumping bans, and cancellation of pesticide registrations. The net result has been an increased tonnage of land-disposed wastes, with adverse impact on public health and the environment. The problem is manifested in groundwater contamination via leachate, surface water contamination via runoff, air pollution via open burning, evaporation, sublimation and wind erosion, poisonings via direct contact and through the food chain, and fires and explosions at land disposal sites. The subject presentation cites case studies that are associated with these various mechanisms of damage.

EPA-660/2-74-055
June 1974

Environmental Protection Technology Series

Physical-Chemical Treatment of Municipal Wastes By Recycled Magnesium Carbonate

Office of Research and Development
U.S. Environmental Protection Agency
Washington, D.C. 20460

EPA-670/2-74-008
January 1974

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WATER POLLUTION CONTROL RESEARCH SERIES • [illegible]

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January 1974

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EPA-R2-73-232
MAY 1973

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Methods for Pulp and Paper Mill Sludge Utilization and Disposal

Office of Research and Monitoring
U.S. Environmental Protection Agency
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WATER POLLUTION CONTROL RESEARCH SERIES • [illegible]

Evaluation of Conditioning and Dewatering Sewage Sludge by Freezing

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Water Pollution Control Research Series

A STUDY OF SLUDGE HANDLING AND DISPOSAL

U.S. DEPARTMENT OF THE INTERIOR
Federal Water Pollution Control Administration

PUBLICATION WP-20-4

EPA-660/2-74-086
December 1974

Environmental Protection Technology Series

Mercury Recovery From Contaminated Waste Water and Sludges

National Environmental Research Center
Office of Research and Development
U.S. Environmental Protection Agency
Corvallis, Oregon 97330

EPA 625/1-74-006

PROCESS DESIGN MANUAL
FOR
SLUDGE TREATMENT AND DISPOSAL

U.S. ENVIRONMENTAL PROTECTION AGENCY
Technology Transfer

October 1974

INDUSTRIAL SLUDGE DISPOSAL PRACTICES*

by

William J. Lacy and Allen Cywin**

The United States Environmental Protection Agency is responsible for establishing national regulations for industrial water pollution control.

These regulations establish the base level for controlling the amount of pollutants that might be discharged to the surface waters of the United States. More stringent requirements may be imposed upon industrial dischargers should these base level limits not be good enough for protecting water quality at the point of discharge.

These limits are to be applied to all similar plants across the country. They are to be in force by July 1, 1977.

In establishing these limits, U.S.E.P.A. is required to consider a number of factors such as the non-water quality impact of the regulations.

There follows selected abstracts referring to sludges from the documents which support the regulations.

Apple, Citrus and Potato

The disposal of most of the solid wastes from the fruit and vegetable processing industry is directed toward animal feed. Solid waste consists of cull fruits and vegetables, discarded pieces, and residues from various processing operations. For example, the net energy and total digestible nutrient content of dried potato pulp is very nearly the same as U.S. No. 2 corn. One exception of waste utilization as animal feed occurs when excessive amounts of pesticides have been used during the growing season.

Screening devices of various designs and operating principles remove large-scale solids such as peel, pulp, cores, and seeds prior to waste water treatment. These solids are then either processed for co-products, sold for animal feed, or land filled.

The solid material, separated during waste water treatment, containing organic and inorganic materials, including those added to promote solids separation, is called sludge. Typically, it contains 95 to 98 percent water prior to dewatering or drying. Some quantities of sludge are generated by both primary and secondary treatment systems with the type of system influencing the quantity. The following table illustrates this:

Treatment System	Sludge Volume as Percent of Raw Waste-water Volume
Dissolved air flotation	Up to 10%
Anaerobic lagoon	(Sludge accumulation in (these lagoons is usually (not sufficient to require
Anaerobic and aerated lagoons	(removal at any time
Activated sludge	10-15%
Extended aeration	5-10%
Anaerobic contact process	approximately 2%

The raw sludge can be concentrated, digested, dewatered, dried, incinerated, land-filled, or spread in sludge holding ponds. In most cases, as stated previously, the sludge goes to animal feed.

Sludge from air flotation with polyelectrolyte chemicals added has proven difficult to dewater, and thereby, presents problems in disposal by any of the above mentioned handling processes. Also, certain polyelectrolyte chemicals rendered the sludge inadequate for animal consumption.

Sludge from secondary treatment systems is normally dewatered or digested sufficiently for hauling and sale as animal feed or fertilizer or for land fill. The final dried sludge material can be safely used as an effective soil builder. Prevention of runoff is a critical factor in plant site sludge holding ponds. Costs of typical sludge handling techniques for each secondary treatment system generating enough sludge to require handling equipment are already incorporated in the costs for these systems.

Silt water from cleaning root commodities such as potatoes is usually handled separately from the food processing water which goes through secondary treatment. The silt water being accumulated in the bottom of the ponds is removed annually and disposed of by adding it to pond dikes. These ponds are generally abandoned after useful performance, with new ponds being established.

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*Presentation at the U.S./USSR "Handling Treatment and Disposal of Sludges and Industrial Residues", Symposium Moscow, USSR, May [illegible].

**Respectively, Directors of the Industrial Pollution Control Division, R&D and Effluent Guidelines Development Division, U.S. EPA, Washington, D.C.

In addition to the solid wastes generated as a result of food processing, solid waste is also generated in terms of trash normally associated with activities. This material may be disposed of at the plant site or collected by the local municipality with disposal by incineration or sanitary land fill. The solid wastes in trash comprise packaging materials, shipping crates, and similar dry combustible materials.

Sanitary wastes are usually handled by a separate system in the plant (in most cases municipal) and consequently are not involved in the food processing waste water treatment. The sanitary wastes are of low volume and quite efficiently treated in standard sanitary waste treatment facilities.

Building, Construction, and Paper

Solid waste control must be considered. The water-borne wastes from the asbestos industry may contain a considerable volume of asbestos particles as a part of the suspended solids pollutant except for the roofing and floor tile subcategories. Best practicable control technology and best available control technology as they are known today require disposal of the pollutants removed from waste water in this industry in the form of solid wastes and liquid concentrates. In some cases these are non-hazardous substances requiring only minimal custodial care. However, some constituents may be hazardous and may require special consideration. In order to ensure long term protection of the environment from these hazardous or harmful constituents, special consideration of disposal sites must be made. All landfill sites where such hazardous wastes are disposed should be selected so as to prevent horizontal and vertical migration of these contaminants to ground or surface waters. In cases where geologic conditions may not reasonably ensure this, adequate legal and mechanical precautions (e.g. impervious liners) should be taken to ensure long term protection to the environment from hazardous materials. Where appropriate the location of solid hazardous materials disposal sites should be permanently recorded in the appropriate office of legal jurisdiction.

Consideration should also be given to the manner in which the solid waste is transferred to an industrial waste disposal area. Solids collected in clarifiers, save-alls or other sedimentation basins should first be dewatered to sludge consistency. Transportation of this asbestos containing sludge should be in a closed container or truck in the damp state so as to minimize air dispersal due to blowing. Precautions should also be taken to minimize air dispersal when the sludge is deposited at the waste disposal area.

The quantities of solids associated with treatment and control of waste waters from paper, millboard, roofing, and floor tile manufacturing are extremely small. For example, the reported volume of dewatered waste solids from a paper plant is 1.5 cu m (2 cu yd) per month. Solids are wasted only when elastomeric binders are being used, which is 25 to 35 percent of the time. Another example is that provided by one of the larger floor tile plants in the country. The sludge and skimmings from the sedimentation unit amount to about 606 liters (160 gallons) per week. Unlike other asbestos manufacturing wastes, this material is highly organic and is disposed of by a commercial firm that incinerates it. The treatment facility at this plant is not highly efficient, but is believed to capture at least 50 percent of the waste solids.

Contrary to the above categories, the waste solids associated with asbestos-cement product manufacture are significant in volume. The reported losses at one pipe plant are in the order of 5 to 10 percent of the weight of the raw materials. The losses of asbestos fibers are kept to a minimum in this industry, to 1 percent or less, and the fiber content of the waste solids is low. The solids have no salvage or recovery value.

In summary, the solid wastes disposal associated with the application of treatment and control technologies in the asbestos manufacturing industry does not present any serious technical problems. The wastes are amenable to proper landfill disposal. Full application of control measures and treatment technology will not result in major increases at most plants. In many cases, complete recycle will result in lower losses of solids.

Beet Sugar Processing

The large volumes of dirt and solid material removed from sugar beets at the processing plant pose a perplexing problem for permanent disposal. Generally, almost 50 kg of soil/kkg (100 lbs/ton) of beets sliced is contributed by a typical beet sugar processing plant. Where holding ponds are employed, solids accumulated in the ponds are removed annually and disposed of by adding the material to pond dikes. These ponds are generally abandoned after useful performance, with new holding pond facilities being established.

Sugar beets stored in large piles at the plant site or in outlying areas such as railroad sidings may be exposed to rodent activity and additional pollution from truck or railroad car unloadings. Rainfall may assist the spread of existing contamination.

In addition to the large volumes of soil delivered to the plant with the incoming beets, solid waste is also generated in terms of truck [illegible] associated with [illegible] processing operations. Disposal of this material may be at the plant site or the waste material may be collected by the local community with disposal by incineration in sanitary landfills. The solid waste as truck [illegible] of [illegible], shipping crates, and similar dry combustible materials.

Sanitary landfills are generally best suited for non-combustible material and organic wastes which are not readily combustible such as [illegible], [illegible], and packing. Incineration offers a viable alternative for disposal of organic materials such as [illegible] [illegible], and packing. Experience with this method in the disposal of combustible wastes has proved more costly than sanitary landfill operations, however. The sanitary landfill is probably the lower cost alternative, provided that adequate land is available.

Consideration of geology is a prime factor in location of a landfill site. Requirements in selection of a landfill site include sufficient area, reasonable haulage distance, location relative to residential developments, soil conditions, rock formations, transportation routes, and location of potential ground water polluting agents. Location of sanitary landfills in sandy loam soils is more desirable. Proper sloping of the landfill and cover to promote runoff rather than ground percolation is necessary to prevent ground water pollution. Other factors to be considered include an elimination of natural drainage channels, installation of protective dikes to prevent flooding when necessary, location of the base of the landfill operation above the high water table, and consideration of possible fire hazards. The general methods and desirable practices in operation of municipal sanitary landfill operations are directly applicable to disposal of solid waste from [illegible] processing plants. Open burning of combustible wastes at the plant site is an undesirable and often unlawful method of solid waste disposal.

Dairy Product Processing

The main non-water pollutional problem associated with treatment of dairy wastes is the disposal of sludge from the biological oxidation systems. Varying amounts of sludge are produced by the different types of biological systems. Activated sludge systems and trickling filters produce sludge that needs to be handled almost daily.

Waste sludge from activated sludge systems generally contains about 1% solids. The amount of sludge produced ranges between 0.05 to 0.1 kg solids per kg BOD5 removed.

Sludge from trickling filters consists of slime sloughed off the filter bed. This sludge settles faster than activated sludge and compacts to solids concentration greater than 1% solids. The amount of sludge produced will be less than that produced by activated sludge systems.

Aerobic and anaerobic digestion of sludge generated from activated sludge systems is recommended to reduce its biomass [illegible] and improve its dewatering characteristics. Sludge thickening can provide [illegible] to improve the digestion operation. Digested activated sludge and stabilized trickling filter sludge can be vacuum filtered, centrifuged or dried on sand beds to increase their solids content for better "handleability" before final disposal.

Flat Glass

Landfilling of properly dewatered sludges from the flat glass industry is an appropriate means of disposal. The wastes are largely inorganic and incineration, composting, or pyrolysis would not be effective in reducing their volume. The dewatered solids are relatively dense and they are stable when used as fill material. If disposed of using proper sanitary landfill techniques, solids from flat glass manufacturing should cause no environmental problems.

With the exception of plate glass manufacturing, the volume of sludge associated with the various control and treatment technologies is relatively small. The lagoons used for plate glass suspended solids removal also serve as sludge disposal sites. The levees are generally raised to keep pace with the rising sediment level. At older plate plants large areas of low-lying land have been filled in. In some cases this is reclaimed as park land by spreading topsoil over the dry sludge solids.

Three types of waste solids are produced by the treatment systems indicated for the float, solid tempered automotive, and windshield manufacturing processes. These are (1) coagulation-sedimentation sludge associated with laminating waste waters, and (2) spent diatomaceous earth, and (3) brine residue associated with at least one treatment alternative for each of the subcategories. The coagulation-sedimentation sludge is assumed to be dewatered by centrifuge to about 10% dry solids and the typical volume produced is estimated to be 0.08 cu m/day (2.8 cu ft/day).

Spent diatomaceous earth has an estimated moisture content of 50% but is dry to the touch. This material is stable and should be suitable for landfill. Estimated production of diatomaceous earth waste is less than 0.23 cu m/day (8 cu ft/day) for each of the subcategories.

The salt residue that will be produced by a total recycle system will present the biggest disposal problem. To prevent ground water contamination, it must be permanently stored in land basins. Only as much water as will evaporate can be allowed into the basin. The land used for salt storage will be permanently spoiled. The salt residue produced by the tempering and laminating processes is conservatively estimated to be 0.85 cu m/day (30 ft/day). Salt storage costs are directly related to the cost of land and the type of lining used.

Grain Processing

The treatment of grain milling waste waters will give rise to substantial quantities of solid wastes, particularly biological solids from activated sludge or comparable systems. Several avenues are available for the disposal of these solids including digestion and landfill, incineration, and other conventional methods of handling biological solids. Alternately, the solids can be dewatered and added to the animal feed already being produced at these mills. This practice has found some acceptance in the grain milling industry, particularly in the corn wet milling segment, and is strongly recommended. Additional discussion of solids recovery and sludge disposal is contained in Section VII.

Unbleached Kraft and Semichemical Pulp

In addition to sludges produced by effluent treatment, the following wastes are or can be produced at mills in the subcategories covered by this survey:

Unbleached Kraft Mills
(and Kraft NSSC)

Bark
Rejects and Screenings
Grits and Dregs
Log wash water
Ash
Waste paper
Garbage
Trash

NSSC Mills

Bark
Rejects and Screenings
Chemical ash
Ash
Waste paper
Garbage
Trash

Paperboard from Waste Paper Mills

Trash
Waste Paper
Fly ash
Garbage

Linerboard mills which bark roundwood on the premises produce sufficient bark to fire a boiler for steam generation so the necessity for its disposal is eliminated. Others receive their wood supply in the form of chips which are a by-product of lumbering operations, and no bark is involved.

Rejects and screenings from linerboard mills are either reprocessed, burned in incinerators or in the bark-fired boilers or disposed of by land fill. The latter procedure represents no problem for most of these mills because of the large mill sites containing considerable usable land. Grits and dregs from the causticizing system of the recovery plant are inorganic solids which are generally water carried to a land disposal site. This is facilitated by their small quantity which amounts to about 22.5 kg/kkg (45 lbs/ton) of pulp produced.

Ash from bark- and coal-fired boilers and screening rejects are as a rule discharged hydraulically to ash ponds. There the solids settle and compact and the clear supernatant water is discharged to the mill effluent system. In some instances, ash and rejects are hauled to a disposal area away from the mill site. Wet handling of these materials avoids their being blown into the atmosphere.

Overflow from log washing operations which contains silt and fine bark particles generally joins the stream carrying ash from the mill.

Waste paper, garbage, and trash attendant to production or accessory operations and activities are either incinerated on the site or hauled away for disposal by contractors engaged in this business.

NSSC corrugating board mills generate most of the kinds of solid wastes created at linerboard mills and handle them in a similar manner. One exception is that most of these mills are relatively small operations which do not produce enough bark to justify a steam-generating bark boiler. The bark is usually disposed of in incinerators designed for this purpose.

At NSSC mills where spent liquor is burned in fluidized bed units, ash consisting of a mixture of sodium carbonate and sodium sulfate is produced. This is usually sold to kraft mills to be used as a make-up chemical replacing salt cake in the recovery system.

The paperboard from waste paper mills, trash such as rags, wire and other metals, glass, and plastics, is removed in the breaker beater and stock cleaning operations. This material, and grit from the rifflers, is disposed of by land fill on the mill premises or hauled to a suitable location for disposal in this manner.

The remaining solid wastes such as ash, waste paper, etc., are handled as described above.

Particulate emissions from incineration of bark and other solid wastes must be controlled by effective devices such as bag filters or scrubbers.

Leather Tanning and Finishing

Solid waste from tanneries and tannery wastewater treatment includes the following: (1) fleshings, (2) hair, (3) raw hide trimmings, (4) tanned hide trimmings, (5) shavings and buffing dust, (6) lime sludge, (7) chrome sludge, (8) biological sludge, (9) grease, (10) general plant trash.

Most tanneries recover fleshings and raw hide trimmings for sale to rendering plants or conversion to glue [illegible] of the tannery site. Tanned hide trimmings are often sold as by-products. Shavings and general plant trash is either hauled away by a local refuse disposal service or disposed of on-site.

In some hair operations, the tannery has facilities for washing, drying, and baling of the hair. The baled hair is sold as a by-product.

Sanitary landfills are best suited for disposal of tannery waste. Incineration and high temperature treatment are not recommended for sludges containing chrome, since chrome may be oxidized from the trivalent to the hexavalent state.

Tannery sludges containing chrome should not be spread on the land until further efforts are made to define the impact of these waste materials upon the environment.

The selection of proper site for landfill operations is of prime consideration. Requirements in the selection include: sufficient area, reasonable haul distance, remote location relative to residential, commercial, and recreational developments, soil conditions and rock formations, accessibility to existing transportation routes, and proximity to existing groundwater supplies. The soil cover should be sloped such that precipitation will run off rather than percolate and pollute ground water sources. Other factors to be considered include provisions to prevent the obstruction of natural drainage channels, location to avoid flood waters, and the consideration of possible fire hazards.

Major Inorganic Products

The [illegible], water soluble solids and water insoluble solids obtained from control and treatment of inorganic chemicals industry water-borne wastes have to be contained, or disposed of, in a safe and economical manner.

Provided that the solids are insoluble in water, most solid wastes from the inorganic chemicals industry may be land dumped or landfilled. Costs are [illegible] to [illegible]/kkg ([illegible] to [illegible]/ton) of solids for simple dumping or landfilling. Large scale operations without cover cost less than [illegible]/kkg ([illegible]/ton). If cover is required for appearance or zoning requirements, the costs may increase to [illegible] to [illegible]/kkg ([illegible] to [illegible]/ton).

If the evaporation-rainfall situation for the disposal area is favorable (as is the case for much of the southwestern U.S. and some other areas of the country), then landfill in an impervious, lined pit is feasible for soluble solids. Operation costs are similar to those for landfill with no cover, [illegible] to [illegible]/kkg ([illegible] to [illegible]/ton).

Landfilling of containerized soluble solids in plastic drums or sealed envelopes is practicable but expensive. Blow-molded plastic drums, made from scrap plastic (which is one of the present major problems in solid waste disposal) could be produced for [illegible]/kkg ([illegible]/ton) capacity at [illegible] kg ([illegible] lb) solids per drum and a rough estimate of [illegible] cost/drum. A more economical method, particularly for large volumes, would be sealed plastic envelopes, 150 microns ([illegible] mils) thick.

At [illegible]/kg ([illegible]/lb) of film low density polyethylene costs about [illegible] per 0.0929 sq m (1 sq ft). Using the film to trench line in a 1.8 m (6 ft) deep trench 1.8 m (6 ft) wide, the perimeter (allowing for overlap) would be approximately 7.6 meters (25 feet). At a density of 1.6 gm/cc (100 lb/cu ft) for the solid, costs of plastic sheet/kkg would be [illegible] ([illegible]/ton). With sealing, the plastic envelope cost would be approximately [illegible]/kkg ([illegible]/ton). With landfill costs of [illegible]/kkg ([illegible]/ton) additional, the total landfill disposal costs would be about [illegible]/kkg ([illegible]/ton).

The above figures for soluble disposal using plastic containers, bags or envelopes are only rough estimates. Also, the technology would not be suitable for harmful solids or in situations where leaching contamination is critical.

Red Meat Processing

Solid wastes are the most significant non-water pollutants associated with the waste treatment systems applicable to the meat packing industry. Screening devices of various design and operating principles are used primarily for removal of large-scale solids such as hair, paunch manure, and hog stomach contents from waste water. These solids may have some economic value as inedible rendering material, or they may be landfilled or spread with other solid wastes.

The solids material, separated from the waste water stream, that contain organic and inorganic matter, including those added to aid solids separation, is called sludge. Typically, it contains 95 to 98 percent water before dewatering or drying. Both the primary and secondary treatment systems generate some quantities of sludge; the quantity will vary by the type of system and is roughly estimated as follows:

Treatment System	Sludge Volume as Percent of Raw Wastewater Volume
Dissolved air flotation	up to 10%
Anaerobic lagoon Aerobic and aerated lagoons	sludge accumulation in these lagoons is usually not sufficient to require removal at any time
Activated sludge	10-15%
Extended aeration	5-10%
Anaerobic contact process	approximately 2%
Rotating biological contactor	unknown

The raw sludge can be concentrated, digested, dewatered, dried, incinerated, land-filled or sub-surface injected on-site, or spread in sludge holding ponds. The sludge from any of the treatment systems, except air flotation with polyelectrolyte chemicals added, is amenable to any of these sludge handling processes.

The sludge from air flotation with chemicals has proven difficult to dewater. A dewatered sludge is an acceptable land fill material. Sludge from secondary treatment systems is normally ponded by the meat industry plants on their own land or dewatered or digested sufficiently for hauling and deposit in public land fills. The final dried sludge material can be safely used as an effective soil builder. Prevention of run-off is a critical factor in plant-site sludge holding ponds. Costs of typical sludge handling techniques for each secondary treatment system generating sufficient quantities of sludge to require handling equipment are already included in the costs for these systems.

Smelting and Slag Processing

The solid waste produced by treatment of waste waters in the industry derives principally from the smelting operation as waste from air pollution control devices. The solid waste from air pollution controls is produced whether a dry or wet system is utilized and varies only in that the former produces a slurry or sludge, the latter a fine dust. The slurry or sludge is generally accumulated in sludge lagoons while the dry dust may be bagged and landfilled or simply piled. More careful attention should be directed to the disposal of these potentially harmful materials. Possible improvements might be landfilling in a sealed site, or encapsulation in concrete or polymers. There has been little success in efforts to agglomerate these solids for recharging to the smelting furnaces, although it is probable that dry dust could be utilized more readily than wet sludge.

Steel Making

Beehive Coke: Solid Waste Disposal: Solid wastes will be generated by processing the scrub water and reusing coke fines in the system.

Sintering: Solid Waste Disposal: The solid waste from the waste system will be internally consumed in the sinter process.

Blast Furnace (Iron): Solid Waste Disposal: There should be no problem in disposing of the solid waste which will be generated. It can be internally consumed in the sinter process plant.

Blast Furnace (Ferromanganese): Solid Waste Disposal: Same as iron making blast furnace (iron).

Basic Oxygen Furnace Operation Semi-Wet Systems: Solid Waste Disposal: The solid waste that will be generated by the fume collection system for the BOF (semiwet) process of steelmaking should present no problem. It can be internally consumed in the sinter process plant.

Basic Oxygen Furnace Operation Wet Systems: Solid Waste Disposal: There should be no problem in disposing of the solid waste generated by the fume collection system for the BOF (wet) process for the manufacture of steel. It can be internally consumed in the sinter process plant.

Open Hearth Furnace Operation: Solid Waste Disposal: The solid waste that will be generated by the fume collection for the open hearth system should present no problem. It can be internally consumed in the sinter process plant.

Electric Arc Furnace Operation Semi-Wet Systems: Solid Waste Disposal: The solid waste that will be generated by the fume collection system for the electric furnace (semiwet) process of steelmaking should present no problem. It can be internally consumed in the sinter process plant.

Electric Arc Furnace Operation Wet Systems: Solid Waste Disposal: There should be no problem in disposing of the solid waste generated by the fume collection system for the electric furnace (wet) process for the manufacture of steel. It can be internally consumed in the sinter process plant.

Vacuum Degassing Solid Waste Disposal: The solid waste that will be generated by the creation of a vacuum for the degassing process should present no problem. It can be internally consumed in the sinter process plant.

Continuous Casting Solid Waste Disposal: The solid waste generated can be consumed internally in the sinter plant.

Synthetic Resins

Biological sludges are the principal disposal problems resulting from end-of-pipe treatment of waste waters. Occasionally chemical sludge (such as from neutralization and precipitation of an inorganic chemical) is of concern. Biological sludges are most frequently subjected to some type of continued biological degradation. Aerobic digestion is the most frequently used method. When lagoons are operated in the extended-aeration mode, the solids accumulate in these lagoons or in polishing lagoons. The long-term consequence of these operations is a gradual filling of the lagoons. They then must be dredged or abandoned. Presently, sludges from end-of-pipe wastewater treatment plants are stabilized by biological means and disposed of to landfills. Prior treatment to dewater the biological sludges by chemical or mechanical means will probably be increasingly employed. However, the problem of landfill disposal remains. Consequently, one of the long-term aspects of waste water treatment is ascertaining that appropriate landfill sites have been obtained. The cost of sludge disposal from plastics and synthetics plants will be essentially equivalent to the cost of sludge disposal from municipal sewage treatment plants. The same type of disposal methods are applicable, but there will be significant variations in the amounts of sludge generated. Estimates based on raw waste loads reported in the Celanese report (8) indicate the range of dry solids to be disposed of would be as follows:

Type of Plant	Units/1000/Units of Product
(1) Cellulosic-based	25-50
(2) Phenolics, epoxy, nylon acrylics, polyesters	10-25
(3) Polystyrene, PVC, ABS/SAN, polyethylene, polypropylene	1-10

Burd (11) reports that lagooning or landfilling cost (capital and operating) is in the range of $1 to $5 per ton of dry solids. Utilizing the higher value, the range of disposal costs per pound of product becomes:

Type of Plant	¢/Pound of Product	¢/kg of Product
(1) Cellulosic-based	0.00625-0.0125	0.0138-0.0276
(2) Phenolics, epoxy, nylon, acrylics, polyesters	0.00250-0.00625	0.00551-0.0138
(3) Polystyrene, PVC, ABS/SAN, polyethylene, polypropylene	0.00025-0.0025	0.000551-0.00551

Burd also reports capital and operating costs for incineration to be $10 to $50 per ton ($11-$55/Mkg). Due to the rapid increase in fuel costs and the relatively small volume of sludge at individual plants, $50 per ton is probably more nearly the cost that will prevail in this industry. Consequently, sludge incineration costs might be expected to be in the following ranges:

Type of Plant	¢/Pound of Product	¢/kg of Product
(1) Cellulosic-based	0.0625-0.125	0.1378-0.2756
(2) Phenolics, epoxy, nylon acrylics, polyesters	0.250-0.0625	0.00551-0.0138
(3) Polystyrene, PVC, ABS/SAN polyethylene, polypropylene	0.00250-0.0250	0.00551-0.0551

The yearly volume of biological sludges (acre feet) generated for each 10,000,000 lbs. of product is estimated to be the following:

Type of Plant	Biological Sludges Only Acre Feet/Year	Cu Meters/Year
(1) Cellulosics and	0.4-0.80	493-986
(2) Phenolics, epoxy, nylon acrylics, polyesters	0.10-0.40	123-493
(3) Polystyrene, PVC, ABS/SAN, polyethylene, polypropylene	0.04-0.10	49-123

The most significant sludge disposal problem is the volume of sludge generated during the removal of zinc from rayon plant waste waters. These sludges, mixed with calcium sulfate, are presently being lagooned. An EPA demonstration project for zinc removal and recovery has been completed. Undoubtedly, the future disposal of zinc sludge will depend upon economics as well as the need to meet effluent limits. Although large diked land areas are required for lagooning and, consequently, large-scale flooding might be considered a hazard, zinc sludge tends to attain a jelly-like consistency, which would prevent this. This means that, if a dike wall breaks, large amounts of the contained sludge will not flow from the filled lagoon.

Petroleum Refining

The major nonwater quality consideration which may be associated with in-process control measures is the use of and alternative means of ultimate disposal of either liquid or solid wastes. As the process Raw Waste Load is reduced in volume, alternate disposal techniques such as incineration, ocean discharge and deep-well injection because of the potential long-term detrimental effects associated with these disposal procedures. Incineration may be a viable alternative for highly concentrated waste streams.

Phosphorus Derived Chemicals

Solid waste disposal will be the chief non-water quality area impacted by the proposed guidelines. Neutralization of acidic waste streams with lime or limestone will increase the amounts of sludge, especially when soluble phosphates and sulfates are precipitated. Installation of dry air pollution control equipment will reduce the water content of wasted solids. In addition, return of collected solids to the process may be feasible. Arsenic rich solid residues accumulate from the purification of phosphoric acid and of phosphorous pentasulfide. Burial in a controlled area is the standard disposal method. Special disposal methods as mentioned previously in this section may be necessary to prevent leachate from reaching surface or ground waters.

Textile Mills

The solid wastes from the textile industry are generally disposed of by landfill. The solid materials, separated during waste water treatment, containing organic and inorganic materials, including those added to promote solids separation, is called sludge. Typically, it contains 97 to 98 percent water prior to dewatering or drying. Some quantities of sludge are generated by both primary and secondary treatment systems with the type of system influencing the quantity. The following table illustrates this:

Treatment System	Sludge Volume as Percent of Raw Wastewater Volume
Dissolved air flotation	up to 10%
Anaerobic lagoon	(Sludge accumulation in
Extended aeration	these lagoons is usually
Aerobic & aerated lagoons	sufficient to require
	removal at any time)
Activated sludge	10 - 15%
Extended aeration	5 - 10%
Anaerobic contact process	approximately 2%

The raw sludge can be concentrated, digested, dewatered, dried, incinerated, land-filled, or spread in sludge holding ponds. Sludge from secondary treatment systems is normally dewatered or digested sufficiently for hauling to a land fill. The final dried sludge materials can be safely used as an effective soil builder. Prevention of runoff is a critical factor in plant-site sludge holding ponds. Costs of typical sludge handling techniques for each secondary treatment system generating enough sludge to require handling equipment are already incorporated in the costs for these systems. All other non-water quality environmental impacts of the alternative treatment and control technologies described appear to be minor.

Tire and Synthetic

Solid waste disposal is a major problem confronting the industry as a whole. Typically 3,100 kg (6,800 lbs) of solid waste are generated by a tire plant each day. Additional solid waste results from the drumming of the waste solutions for off-site disposal. Many manufacturing plants, particularly in the northern states, are finding it difficult to locate and arrange for service at a satisfactory landfill sites. Fortunately, the additional solid waste generated by the proposed treatment technology is very small relative to the normal solid waste generated by the production facility.

Sludge cake is produced by vacuum filtration of the primary coagulation solids and the digested biological solids. Sludge disposal costs were based on sanitary landfill. Sludge incineration costs were not evaluated because the economics depend, to a large degree, on the accessibility of a landfill site and on the relative costs for sludge haulage and site disposal. The annual quantities of solid waste generated are:

Primary coagulated solids	2,940 cu m (3,900 cu yd)
Biological solids	245 cu m (325 cu yd)

Solid wastes are produced by chemical coagulation and clarification, wasted biological sludge, and spent activated carbon. For cost purposes, it is proposed that these all be hauled to a landfill. The annual quantities of solid wastes are listed below:

Primary coagulated solids	214 cu m (283 cu yd)
Biological Solids	62 cu m (82 cu yd)
Spent carbon	136 cu m (167 cu yd)

Solid waste generation with this treatment system is associated with biological solids and spent activated carbon. The activated carbon canisters may be returned for regeneration off-site by the supplier. However, annual operating data have been based on disposal of the spent carbon at a landfill site. The annual quantities of solid waste generated are:

Biological solids	102 cu m (135 cu yd)
Spent carbon	140 cu m (185 cu yd)

Synthetic Resins

Biological sludges are the principal disposal problem resulting from end-of-pipe treatment of waste waters. Occasionally chemical sludge (such as from neutralization and precipitation of an inorganic chemical) is of concern. Biological sludges are most frequently subjected to some type of continued biological degradation. Aerobic digestion is the most frequently used method. When lagoons are operated in the extended-aeration mode, the solids accumulate in these lagoons or in polishing lagoons. The long-term consequence of these operations is a gradual filling of the lagoons. They then must be dredged or abandoned. Presently, sludges from end-of-pipe wastewater treatment plants are stabilized by biological means and disposed of to landfills. Prior treatment to dewater the biological sludges by chemical or mechanical means will probably be increasingly employed. However, the problem of landfill disposal remains. Consequently, one of the long-term aspects of wastewater treatment is ascertaining that appropriate landfill sites have been obtained. The cost of sludge disposal from plastics and synthetics plants will be essentially equivalent to the cost of sludge disposal from municipal sewage treatment plants. The same type of disposal methods are applicable, but there will be significant variations in the amounts of sludge generated. Estimates based on raw waste loads reported in the Celanese report (8) indicate the range of dry solids to be disposed of would be as follows:

Type of Plant	Units/1000/Units of Product
(1) Cellulosic board	25-50
(2) Phenolics, epoxy, nylon acrylics, polyesters	10-25
(3) Polystyrene, PVC, ABS/SAN, polyethylene, polypropylene	1-10

Burd (11) reports that lagooning or landfilling cost (capital and operating) to be in the range of $1 to $5 per ton of dry solids.

Utilizing the higher value, the range of disposal costs per pound of product becomes:

Type of Plant	¢/Pound of Product	¢/kg of Product
(1) Cellulosic board	0.00625-0.0125	0.0138-0.0276
(2) Phenolics, epoxy, nylon, acrylics polyesters	0.0025-0.00625	0.00551-0.0138
(3) Polystyrene, PVC, ABS/SAN/ polyethylene polypropylene	0.00025-0.0025	0.000551-0.00551

Bard also reports capital and operating costs for incineration to be $10 to $50 per ton ($11-$55/kkg). Due to the rapid increase in fuel costs and the relatively small volume of sludge at individual plants, $50.00 per ton is probably more nearly the cost that will prevail in this industry. Consequently, sludge incineration costs might be expected to be in the following range:

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(1) Cellulosic-based	0.0625-0.125	0.1378-0.2756
(2) Phenolics, epoxy, nylon acrylics, polyesters	0.250-0.0625	0.00551-0.0138
(3) Polystyrene, PVC, ABS/SAN, polyethylene, polypropylene	0.00250-0.0250	0.00551-0.0551

The yearly volume of biological sludges (acre feet) generated for each 10,000,000 lbs of product is estimated to be the following:

Biological Sludges Only

Type of Plant	Acre Feet/Year	Cu Meters/Year
(1) Cellulosic-based	0.4-0.80	493-986
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The most significant sludge disposal problem is the volume of sludge generated during the removal of zinc from rayon plant wastewaters. These sludges, mixed with calcium sulfate, are presently being lagooned. An EPA demonstration project for zinc removal and recovery has been completed. Undoubtedly, the future disposal of zinc sludge will depend upon economics as well as the need to meet effluent limits. Although large diked land areas are required for lagooning and, consequently, large-scale flooding might be considered a hazard, zinc sludge tends to attain a jelly-like consistency, which would prevent this. This means that if a dike wall breaks, large amounts of the contained sludge will not flow from the filled lagoon.

SUMMARY

Considerable work has been done and is being reported in this conference on residual recovery and reuse. Examples include the recovery of product fines, usable water and thermal energy. There are many products that are recovered now but there are many more that could be recovered in the future.

A trend by industry in the direction of "closing the loop" has been established and it is becoming obvious that it may be an intelligent thing to do. Accordingly, Effluent Guidelines Development Program with the technical base of the EPA industrial research, development, and demonstration (RD&D) program is oriented toward the elimination of discharge of pollutants into the navigable waters of the U.S.A.

Waste treatment must be considered not an add-on but an integral part of the manufacturing process and the cost of treatment must be charged against the product. The waste disposal operations result in a net cost to the industry producing the waste, but you will hear at this conference examples of how product recovery and utilization practices reduce the cost of treatment and frequently prove to be cheaper than other methods of disposal.

In the treatment of industrial discharges, by-product recovery frequently accompanies water reuse and water conservation. Recycled water may ultimately be the major valuable product because of increasing water supply costs, increasing water treatment costs, and mounting charges for using municipal sewerage facilities.

Industrial wastes contain the gamut of toxic chemicals, hazardous materials and heavy metals. Direct discharge of these wastes into streams and rivers is objectionable as this is a gross insult to the environment. These wastes cannot be sent through sewage treatment plants as they contain toxic materials. Hence, the pretreatment and reduction of waste load is of importance in the waste treatment plant operations.

Frequently, waste streams can be eliminated or reduced by process modifications or improvements. A notable example of this is the use of save rinse and spray rinse tanks in plating lines or dry caustic peeling and hot air blanching in the canning industry. These measures bring about a substantial reduction in waste volume and a net savings of energy, conservation of materials and protection of our environment, not to mention being more economical.

In closing, I want to again thank you for the opportunity of addressing you today and leave this thought that both industry and government must become attuned to "WASTE NOT WANT NOT" or "A PENNY SAVED IS A PENNY EARNED" philosophy in the future to preserve the environment and protect our national resources.

THICKENING AND DEWATERING OF WASTE WATER SLUDGES BY VIBRO FILTRATION METHOD

by

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[illegible]

Present day methods of mechanical dewatering, that is, vacuum filtration and centrifugation in most cases require sludge conditioning that considerably complicates and increases the cost of the sludge treatment process. The application of vibro-filtration method in sludge thickening and dewatering without addition of chemicals is of concern.

Vibro-filtration as a new trend in the separation technology of industrial suspensions has been recently introduced. The main feature of this type of filter is the use of vibrations of filtering media in order to intensify the liquid-solid separation process. The destruction of sludge structure and the reduction of its resistance to filtration, the continuous regeneration of filtering media and furthermore, the increase in working pressure differential caused by arising inertial forces take place during the separation process.

Depending upon the objective of filtration and properties of filtered suspensions pressure or open (gravity flow) vibrofilters are used.

The Gravity flow vibro-filters with harmonic vibrations of filtering media with frequency of 100 Hz are being more widly used for thickening and dewatering of industrial suspensions and waste water sludges. The dewatering process occurs at the movement of thickened sludge, produced by directed vibrations or filtering media slope.

We have carried out theoretical and experimental investigations of waste sludge dewatering process on a model of continuous gravity vibro-filter with directed vibrations of the filtering media in the frequency range of 30 to 100 Hz and the acceleration to 10g.

The studies were conducted on municipal and industrial sludges. The construction of the joint of the model to a vibration stand permitted to change the angle of filtering media slope α in the range of 0 - 18° and the direction of vibrations β from 30 to 90° (Fig. 1). The VEM - 200 vibration stand allowed to regulate continuously the frequency of 30 to 100 Hz and the acceleration of vibrations of 1 to 10g.

Metal screens with 40-130 microns meshes were used as a filtering media. The studies of the relationship of filtration rate to vibration parameters were conducted on filling filtration funnels. The filming was used to record the rate of the process. The investigations of process kinetics showed that vibro-filtration process occurred in two stages in the absence of excess static pressure Fig. 1.

First the layer of vibro-fluidized sludge with solids concentration C_1, that is higher than solids concentration of incoming suspension, C_0 forms on the filtering screen. The resistance to filtration of this layer depends on the degree of its fluidization, that is on vibration parameters of the screen and on the depth of the layer, on the other hand. The solids concentration in the suspension above the layer is equal to the solids concentration in initial suspension. When the layer of incoming suspension above the sludge layer reduces to zero the first stage of filtration process finishes and the second one starts, during which the reduction of the sludge layer occurs due to the separation of filtrate. The solids concentration in the layer constantly increases, but solids concentration gradient on the layer depth stays equal to zero throughout the second stage of filtration process.

Mathematical model of both stages of the process was obtained on the basis of linear law of filtration.

Equation 1

$$\frac{dV}{dt} = K_0 \frac{P}{\mu L} S; \quad V = U \cdot S; \quad U = l + H$$

where

V volume of suspension;
K_0 coefficient of permeability;
μ kinematic coefficient of viscosity of liquid phase;
P pressure differential;
L length of filtration path;
S area;
t time;
U total depth of suspension layer above filtration media;
l depth of vibro-fluidized sludge layer;
H depth of suspension layer above sludge layer.

Both stages of vibro-filtration process are schematically presented in Fig. 1.

The driving force of the process P consists of hydrostatic pressure P_h (V) determined by the depth of the filtered suspension above filtering screen, and pressure $P_a(V)$ arised in the suspension by the action of inertial forces.

Equation 2

$$P = P_0(V) + P_a(V) = \frac{G}{F} + \frac{G}{gF}a = \frac{G}{F}(1 + A)$$

where

a – mean value of vibration acceleration;
G – weight of suspension;
A – relationship of vibration acceleration to gravity acceleration.

$$A = \frac{a}{g}; \quad a = A\omega^2$$

Having determined the sludge weight through its volume for each stage of filtration process respectively in Eq. 2, after integration we obtain the mathematical description for both stages of vibro-filtration process.

The first stage is described by Eq. 3

$$t = \frac{V_0 M + U}{B} \ln \frac{V_0 M - U}{V M - U} - \frac{V_0 - V}{B} M$$

where

$$M = C_0 + \frac{C_0^2}{C_T - C_0} + \gamma; \quad U = V_0 C_0 \left(\frac{C_0}{C_T - C_0} + \frac{\gamma}{\gamma_T}\right);$$

$$B = \frac{K_{01} M^2}{\gamma F}(1 + A) S^2 \frac{C_T - C_0}{C_0};$$

γ, γ_T are specific weights of liquid and solid phases.

K_{01} constant coefficient, determining resistance to filtration of the vibro-fluidized sludge layer during the first stage of filtration.

The second stage of vibro-filtration process is described by equation 4

$$\frac{V_0 C_0 (V_1 - V)}{(V_1 - V_0)(V - V_0)} + \ln \frac{V - V_0}{V_1 - V_0} = \frac{B_0}{V_0} S (t - t_1)$$

where $B_0 = \frac{K_{02}(1 + A)}{\mu} \gamma$;

V_1 sludge volume above filtering screen at the beginning of the second stage when $t = t_1$, and V_0 is sludge volume when $t = \infty$; K_{02} experimental coefficient responsible for resistance of vibro-fluidized sludge layer during the second stage of filtration.

The typical kinematic curve of activated sludge vibro-filtration with initial concentration of 6.5 g/l at vibration frequency of filtering media of 50Hz and acceleration of 4g is presented in Fig. 4.

The experimental values are shown as points. The curve AC and AD are calculated according to equation of both stages on the basis of experimental values of K_{01} and K_{02}.

The curve AC describes the first stage of vibro-filtration process with the formation of vibro-fluidized sludge layer on the screen as it is evident from Figure 4, the curve is in satisfactory agreement with experimental values to a certain time t_1 then deviates downward. It means that by the moment of time t_1 the first stage finishes and the second one starts. As experimental data showed, the vibro-filtration process of organic sludges occurred in two stages when solids concentration in sludge is less than 15 g/l. As the concentration of incoming organic sludges usually is higher therefore only the second stage of dewatering process of this type of sludges takes place.

Qualitative investigations of the process with the use of high-speed filming showed, that in the course of filtration the sludge layer didn't separate from the porous media even at the acceleration of 8-10g.

The final moisture of sludge depends on the acceleration and the frequency of vibrations, and for tested sludges dewatered at frequency of 50Hz and the acceleration of 8g during the same time was as follows:

for thickened activated sludge 93-94%
for primary sludge 84-86%
for digested coagulated sludge mixture 82-83%
for the mixture of primary and thickened activated sludges 86-88%
for sludges from wood fibred slabs plants 82-86%
for sludges of blast-furnace gas-cleaning process 35-38%

The solids content in the filtrate depends on the vibration parameters of porous media, its permeability and sludge properties.

One more significant feature that is, the screen must be rigid should be taken into consideration besides common requirements for filtering media. So metal screens were used during experiments. The application of synthetic cloth didn't give positive results during dewatering of waste water sludges.

The cloth dissipates the energy of vibrations, not transferring it to the sludge layer.

The relationships of filtrate concentration to vibration parameters have a parabolic shape. These dependences have almost the same character for all investigated sludges, and differ in numerical values of filtrate concentration. As the major amount of filtrate is produced at the beginning of the process in order to minimize losses of solids with filtrate, it is better to carry out the dewatering process in two stages: maximum possible thickening of sludge at accelerations in the range of 3 of 5 g, and subsequent dewatering of sludge to produce a cake with minimum moisture at acceleration of 8-10 g.

In this case the loss of solids with filtrate is considerably reduced. The results of these studies indicated, that the dewatering of waste sludges in the frequency range of 30 to 50Hz is optimal.

The dewatering of sludge on the gravity vibro-filters occurs at the sludge movements on the filtering caused by the action of directed vibrations. Therefore the direction of vibrations β and the angle of filtering media slope above the horizontal α belong to the basic parameters of vibro-filtration process. The relationship of rate of movements to vibration parameters was obtained experimentally (Eq. 5):

$$U_{np} = E\left(\frac{A\omega^2\sin\beta}{g\cos\alpha}\right)^{0.6} A\omega^{0.33}\cos\beta\,\beta^{0.5}\left(\frac{\alpha_{np}-\alpha}{\alpha_{np}}\right)^{0.1}$$

where α_{np} angle of slope, at which the vibration movement of sludge stops (its value for tested sludges is from 12-15°).

It was found experimentally, that the angle β is 55-70°), angle α 6-8° at the dewatering of sludges under optimum conditions.

The results obtained on bench-scale continuous vibro-filter unit during vibrofiltration process are given in Table 1.

According to the results of investigations the pilot model of vibro-filter was developed and constructed and will be applied in the dewatering of sludges from pig-breeding farms.

Considerable losses of solids with filtrate and relatively high final moisture of dewatered sludge reduce efficiency of vibro-filtration process.

Nevertheless the analysis of experimental results shows, that vibro-filtration belongs to the promising developments in the field of intensification of thickening and dewatering of some types of sludges and permits to separate the considerable part of free water from sludge without conditioning.

Approximated technical-economic calculations indicate that the use of sludge vibro-thickening with consequent heat drying or incineration in most cases allows to exclude complicated and expensive conditioning process prior to mechanical dewatering from the technological scheme.

However additional expences on heat will be required but the cost of extra fuel doesn't exceed expenses on addition of chemicals and dewatering.

TABLE 1

Type of sludge	Initial moisture content (%)	1st stage Thickening process: Final moisture content (%)	1st stage Thickening process: capacity kg/sq m per h	2nd stage Dewatering process: Final moisture content (%)	2nd stage Dewatering process: capacity kg/sq m h	Total capacity kg/sq m	Solids loss %
1 Primary sludge	93-94	89-90	60-70	84-86	60-90	80-90	15-20
2 Thickened activated sludge	97.5-98	95.5-96.5	12-16	93-94	20-30	7-12	8-12
3 The mixture of primary and thickened activated sludge	96.6	92-94	30-35	86-87	50-65	30-35	8-15
4 Primary sludge from wood-fibred slab plant	98-98.5	91-93	50-60	85-87	100-110	15-30	10-15
5 Sludge from wet blast furnace gas cleaning process	75-80	35-42	900-1100	28-32	1000-1200	1050-1200	12-15

Figure 1. Bench scale vibro-filter unit.
1. Vibrator.
2. Filtering screen.
3. Feed sludge.
4. Dewatered sludge.
5. Filtrate.

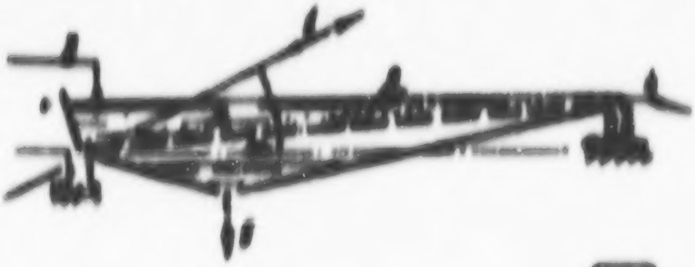
Figure 2. Schematic diagram of a laboratory unit for investigation of vibro-filtration process.
1. Vibrator.
2. Filtration funnel.
3. Sampling pipe.
4. Cylinder volume.
5. Camera.

Figure 3. Vibro-filtration process.
1st stage of vibro-filtration process.
2nd stage of vibro-filtration process.

Figure 4. Kinetics of activated sludge vibro-filtration.

СХЕМА МОДЕЛИ ВИБРАЦИОННОГО ФИЛЬТРА

$0^\circ \leq \alpha \leq 15^\circ$ $20^\circ \leq \beta \leq 90^\circ$



1 ВИБРАТОР
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3 ИСХОДНЫЙ ОСАДОК
4 ОТЖАТЫЙ ОСАДОК
5 ФИЛЬТРАТ

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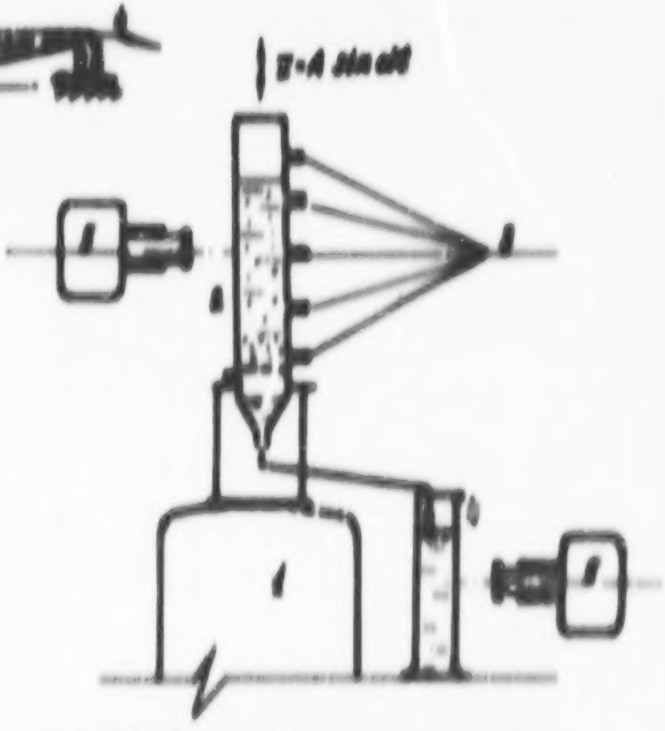

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3 ШТУЦЕРА, 4 МЕРНЫЙ ЦИЛИНДР,
5 КИНОАППАРАТ.

РИС 2.

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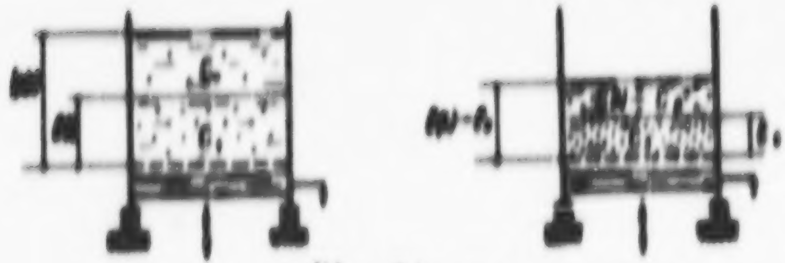

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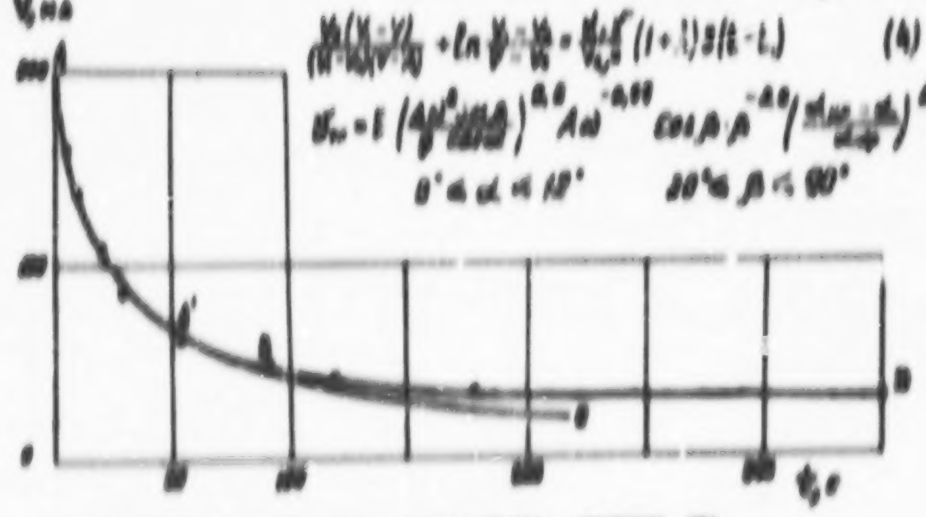

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MUNICIPAL SLUDGE MANAGEMENT RESEARCH PROGRAM IN THE U.S.A.

BY

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PRESENTED AT
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HANDLING, TREATMENT AND DISPOSAL OF SLUDGES
MOSCOW, USSR
May 1975

MUNICIPAL SLUDGE MANAGEMENT PRACTICE AND RESEARCH PROGRAM IN THE U.S.A

INTRODUCTION

The United States Environmental Protection Agency, Municipal Wastewater Sludge Research and Development program is designed to resolve the health and ecological issues and to preserve and utilize this resource in a beneficial manner.

I don't know if there is a similar expression in your language, but there is an old expression in English appropriate to this approach to solving sludge problems. It is: "make a silk purse out of a sow's ear".

The persons attending this Symposium, on both sides, are aware of the complexities of sludge management systems and the difficulties that must be overcome in finding environmentally acceptable solutions.

We view our approach or research plan as having the primary purpose of developing and demonstrating new or improved technology which can be placed into practice throughout the United States.

Ours is not completely a government program. It is a cooperative program conducted in partnership with the Water Pollution Control Agencies and Universities of our States, local governments, industry and other Agencies within the Federal government. The difficulties of processing, utilizing and disposing sludge are faced by the local communities. We, therefore, look to them for participation by testing the newest technology under local conditions where the practicability, efficiency, cost and operating problems can be determined under actual operating circumstances.

Industry participates through its development programs and manufacturing capabilities. It is advantageous to individual companies because the market potential for equipment and systems is improved if performance and cost data are available from full scale projects.

Environmental concerns are the principal driving force behind the effort to develop improved technology. They range from undesirable odors to the potential for contaminating the human food chain when sludges are placed on agricultural land. The engineering aspects, such as improved means of dewatering, have cost factors and simplicity of operation as driving forces.

Utilizing the partnership arrangement mentioned earlier, we view the program as a broad-based approach to problem solving.

We first recognize the environmental constraints imposed by the nature of the sludges. These constraints are imposed by the constituents of environmental concern: the trace metals, bacteria, viruses, intestinal parasites, process chemicals contributed by industry, nutrient materials, organics and PCB's (Polychlorinated biphenyls).

The technology improvements we are developing must be designed to produce an end product which has either removed or inactivated the problem constituents. Hopefully, that objective can be accomplished by simultaneously producing a useful product or by serving a useful purpose, such as power production.

Our discussions with your experts here in the Soviet Union in 1973 and again in the United States in 1974 clearly indicated that the sludge problems faced here are not substantially different from those in the United States or, as a matter of fact, in all of the urbanized areas of the World. Approximately 60 percent of the municipal sludge generated in the United States is currently being applied to the land in a number of ways including liquid spreading, landfill and trenching (see Table 1).

Without clear delineation of environmental impact and public health factors associated with land application, we cannot be assured, or even confident, that current practices do not adversely affect our environment. Once the damage is done, it is extremely difficult to undo. Nitrate contamination of a groundwater aquifer due to placement of sludge on the land, for example, will exert its effect for many years. We are, therefore, studying the health and ecological factors involved in land application of sludge.

At the same time, we are evaluating technology which can be employed to eliminate or minimize specific problems. Pasteurization, other heat treatment methods and lime stabilization are being studied as alternatives for resolving the bacterial, virus and intestinal parasite issue.

A cooperative effort with the U.S. Department of Agriculture and the Food and Drug Administration is directed to the definition of the impact of trace metals on the human food chain through the production of crops and meats grown on land to which sludge has been applied. Evaluation of the uptake of metals in the crops, and in animals grazed on land to which sludge has been applied are part of this effort. Studies of this type in the United States and in other countries should provide the information needed to establish guidelines which will inform the users of municipal sludges of the limitations of use applicable to the constituents of concern. They will also provide guidance on the techniques of application which will permit them to utilize sludges in an acceptable manner.

I wish to note here, since the technical problems are so similar, that we are also conducting extensive studies of land application of treatment works effluents.

Incineration will be discussed in detail by others during the Symposium. Since about 25 percent of the municipal sludge generated in the United States is disposed by means of incineration, I would note at this point that the technical questions concerning the environmental aspects of this method have not been settled to complete satisfaction. Air emissions of some of the sludge constituents, such as the metals and PCB's are still of concern to local authorities. This is not to say that incineration is not an acceptable means of sludge disposal. It can be a satisfactory disposal means. As I have already indicated, others will discuss these matters in more detail.

While sludge utilization and disposal is a problem to some degree for each municipality and for those who plan and oversee pollution control remedial activities, the coastal metropolitan areas have a problem of larger proportion. Approximately 15 percent of the municipal sludge produced is ocean dumped. Recent legislation requires control of the dumping of hazardous materials to the ocean. All who would dispose of such materials at sea must now do so only with a permit issued by the Environmental Protection Agency. Municipal sludges, because of their constituents, fall under the requirements of this legislation. It is planned that ocean dumping of sludges will be discontinued within the next few years, which removes a major disposal alternative from the hands of municipalities along the coast. Land-based alternatives must then be utilized. Scarcity of suitable sites for land application within reasonable hauling distance, air pollution control requirements and socio-economic aspects then place additional pressures on those who seek environmentally acceptable sludge technology.

Table 1 outlines the direction of research and development referenced early in this presentation. We hope to include any technology which offers potential for cost effective solutions. Environmental constraints cause us to examine technologies such as pasteurization and sterilization for solution of problems identified with bacteria, viruses and intestinal parasites when applying sludge to the land. Other heat treatment technologies such as the Porteous process, will also contribute to the solution and improve dewatering characteristics.

Wet oxidation offers the potential for sterilizing the sludge and to produce useful by-products including thermal energy and saleable chemicals such as acetic acid. Application of this method may also make it feasible to recover trace metals from the sludge. The small amount of residual solids from the wet oxidation process is sterile and should pose no major problem of disposal.

Composting and heat drying are being studied in respect to the use of the resulting materials for soil conditioners and low-grade fertilizers. When properly applied, these methods also produce a material which is acceptable from the standpoint of biological quality.

Pyrolysis offers the potential, especially when sludge is utilized in combination with municipal, solid wastes, to accomplish large reduction in volume, production of low BTU gas, tars and oils and other useful materials.

Coincineration with solid wastes in systems which will include heat recovery or power production may be an applicable approach and is under study.

Application of these new approaches to solution of the "sludge problem" is in the development stages. A wet-oxidation process which offers a great deal of potential will be built and tested at pilot scale within the next two years.

Each technology has its specific advantages and disadvantages. The costs, operation and maintenance and general acceptance of each will determine how it is used or considered for application in different locations.

Recognition is being given to socio-economic aspects of the problem as we proceed with the program. The experience of many communities indicates that successful application of any of the technologies will depend to a significant extent on public acceptance. This is a factor too often ignored in planning a sludge system for incorporation into the plans for wastewater management systems. Those who would be subjected to odors, groundwater contamination, air emissions or other impact on the environment should have a say in what technology is applied. If we accept that as a requirement for sludge systems we must recognize that careful evaluation of all technologies is of first importance. Such evaluation will be of limited value, however, if we do not also effectively communicate this information to the public.

During the past five to eight years improvements in process have been made and technologies previously little used or new to United States practice have been introduced and evaluated by means of demonstration projects. These include pressure filtration, top-feed vacuum filter, lime stabilization, heat treatment, land disposal by trenching, aerobic digestion, composting and land reclamation.

These are tools communities can use in combination with traditional processes such as anaerobic digestion, flotation thickening, incineration, and others to form sludge management systems currently satisfactory for a large number of locations.

They do not, however, provide all the answers for solving the most difficult sludge management problems faced by the larger cities and cities located in areas where potential environmental damage is a major problem.

For this reason we are proceeding with a research program directed to the development and demonstration of technology not previously applied or adapted to sludge management. Pyrolysis and wet-oxidation are examples of processes which fall in this category. Such emphasis is of recent beginning and it will be two or three years before sufficient data will be available to make judgements with regard to applicability and cost effectiveness of the new processes. With moderate success it will be possible to formulate new sludge management systems, improve system efficiency and cost factors and ultimately to demonstrate that sludge can not only be managed in an environmentally acceptable manner, but can also be an asset to the environment.

SLUDGE HANDLING ALTERNATIVES

In general, as a treatment plant's effluent improves, greater quantities and more complex types of sludge are produced. These are the factors that make sludge treatment and disposal such a great challenge. Sludge handling processes can be classified as shown in Fig. 1. Within each of these categories are listed numerous process alternatives. The challenge in putting together a total process is the evaluation of the numerous alternatives and the elimination of inappropriate methods. Little comment is required about the need for thickening other than the fact that it is used to increase a sludge's solids concentration while maintaining fluidity. Sludge stabilization processes aim at converting raw or untreated sludges into a less offensive form with regard to odor, rate of putrefaction and pathogenic organism content. Sludge conditioning is a pretreatment of thickening or dewatering process. A dewatering method removes sufficient water from sludge so that its physical form is essentially changed from that of a fluid to that of a damp solid. Most of the techniques shown in Fig. 1 are familiar to the pulp and paper industry. One dewatering technique that is relatively new and has potential for solving future and present problems is the belt filter press. Several manufacturers are currently marketing in the United States variations of a horizontal belt filter press. One such device is shown in Fig. 2. These devices generally utilize the following steps: chemical conditioning possibly followed by gravity thickening and introduction of the conditioned and thickened sludge onto a porous belt with simple pressure or "squeezing" of the sludge by roller-pressing; combined pressing and shearing of the cake; and finally, discharge of the sludge cake. In some designs, the porous belt is actually a capillary material or a slight vacuum is applied before squeezing the sludge. These devices are undergoing steady development and offer potential benefits of low capital and maintenance cost, simple operation, and a higher cake solids than centrifuges or vacuum filters.

Sludge reduction processes are those that yield a major reduction in the volatile sludge solids (see Fig. 1). None of the techniques shown are strangers. Incineration and wet oxidation are well-known processes, but there have been no full-scale applications of pyrolysis of sewage sludge as yet. Final disposal methods, the last classification shown in Fig. 1, refer to the disposition of sludge in liquid, cake, dried, or ash form as a residue to the environment. Essentially all the techniques shown are self-explanatory.

In the above presentation of methods available for the treatment and disposal of sludge, the discussion followed the process flow sequence, that is, sludge was taken from the clarifier through various treatments and finally disposed. Actually, the disposal procedure should be determined first, since its selection often dictates the choice of treatment methods. For example, if a sludge is to be incinerated, biologically stabilizing it would be highly undesirable since this would reduce the sludge's volatile solids content and, therefore, its caloric content. Effectively thickening and dewatering the sludge would, however, be desirable since this minimizes the need for auxiliary fuel in burning.

Total costs for some sludge handling processes are given in Table IV. Major expenses are associated with the mechanical dewatering, digestion, and incineration processes, while gravity thickening is low in cost.

IMPACT OF UPGRADING WASTEWATER TREATMENT BY THE ADDITION OF CHEMICALS ON SLUDGE PRODUCTION

Adding chemicals such as alum, lime, ferric chloride or polyelectrolytes in the primary and secondary treatment processes can upgrade present treatment plant efficiencies. The chemicals enhance the removal of suspended solids, BOD, and phosphorus. Better removal of suspended solids in the primary clarifier, however, also increases primary sludge production and decreases waste activated sludge production. The total mass of sludge solids to be dewatered will increase primarily due to greater removal of incoming solids and the precipitates formed by the chemical additives.

Knowing what happens to the sludge mass and volume when chemicals are added into the treatment processes is of considerable interest. Although data are very limited, some have been obtained for phosphorus removal systems from a review of 13 case histories, which include both pilot and plant scale studies (3). Table V shows the effect of adding chemicals in primary treatment. Although with lime addition the sludge solids concentration was either changed only slightly or greatly increased depending upon the amount of lime added to the wastewater, the sludge mass and volume were considerably increased. With aluminum (Al+++) and iron (Fe+++) addition, sludge mass increased but not to the extent that occurred with lime. Sludge volume, however, was equal to or greater than that obtained with lime. Addition of Al+++ and Fe+++ clearly had a detrimental effect on the sludge solids concentration. Similar data for the addition of Al+++ and Fe+++ not to the primary clarifier but to the activated sludge process are given in Table VI. Although large increases in sludge solids and volume occurred, surprisingly, the sludge solids concentration was not as seriously affected as it was with the addition of Al+++ and Fe+++ salts to the primary system. Table VII shows the effect of tertiary treatment by lime, Al+++, and Fe+++ addition on sludge production. In each case, a large amount of dilute sludge solids was produced. The smallest amount of sludge mass was produced with iron addition, the greatest with lime.

The data just presented clearly indicate that the addition of chemicals in wastewater treatment can cause large increases in the mass and volume of sludge to be processed. With the addition of Al+++ and Fe+++ salts, the resultant sludge may be very dilute (1 to 2% solids). Further the use of inorganic chemicals increases the inorganic content of the sludge, which means there will be more ash to dispose of if the sludge is incinerated, and the sludge will have a lower volatility and, therefore, lower calorific content. Plants employing chemical addition will probably need a more elaborate and costly sludge treatment and disposal scheme than that used with conventional sludges. Learning that more complete wastewater treatment can produce additional sludge disposal burdens is not a new experience. When only primary sludge was produced, the operator had a simple fibrous material to work with. It was basically incompressible, generally came from the clarifier with a solids concentration of about 5%, and could be readily gravity thickened to an 8 to 10% solids concentration. With little chemical conditioning, this material is readily dewatered by a rotary vacuum filter at rates of from 24 to 49 kg D.S.*/m² hr (5 to 10 lb D.S./ft² hr), and high cake solid concentrations of from 25 to 30% result. The sludge cake was often autocombustible. A completely different situation arose with the need to handle large quantities of waste activated sludge. This material typically leaves the clarifier with a very dilute solids concentration of from <1 to 1.5% and is gelatinous in nature. The sludge is generally very compressible and will only thicken by gravity to about a 2.5% solids concentration. Even with considerable chemical conditioning, it dewaters on a rotary vacuum filter only poorly. Consequently few plants dewater straight waste activated sludge. It is generally first mixed with primary sludge, and this combination is thickened and dewatered. The combination, however, typically dewaters more poorly than the primary sludge alone.

IMPACT OF CHEMICAL ADDITION IN PRIMARY TREATMENT ON SLUDGE HANDLING

The difficulty faced in handling chemical process sludges sparked the initiation of a research project to define the ability of conventional thickening and dewatering techniques to process chemical-primary sludges. At Salt Lake City, Utah, the Envirotech Corporation, under contract to the U.S. EPA, has been studying the characteristics of sludges produced when either Fe+++ or Al+++ salts are added to raw wastewater. A dual train pilot system, each train of which has the capacity to process 152 l/min (40 gpm), is operated on raw wastewater. Each train consists of a primary clarifier, with sludge removal to a thickener. An Fe+++ salt is added to remove phosphorus in one train and Al+++ salt is added in the other train. Phosphorus-laden chemical primary sludges thus produced are studied as to their thickening characteristics in gravity and dissolved air flotation pilot systems and as to their dewatering characteristics by pilot vacuum filtration and centrifugation units (4). Preliminary results of pilot scale gravity thickening tests are presented in Table VIII. The solids concentration in the sludge leaving the clarifier in the Fe+++ salt-dosed train was slightly higher than that leaving the clarifier in the Al+++ salt-dosed train. In each case, indications are that a sludge's thickening properties vary inversely with the quanity of Al+++ or Fe+++ it contains, and the chemical primary sludge thickens better when polyelectrolyte is added to the wastewater. In general the Al+++ sludge thickened very poorly. The best results were obtained with the sludge produced from a low Al+++ and polymer dosage to the raw wastewater. A feed sludge of about 1.7% solids was generated. When this feed sludge was loaded to the thickener at a rate of 20 kg D.S./m² da (4 lb D.S./ft² day), a solids concentration of 4.7% was produced. The Fe^{+++} sludges thickened much better than the Al^{+++} sludges. Similar thickening results were obtained for the sludge produced when polymer and both high and low levels of Fe^{+++} were added to the wastewater. Best results were obtained for a feed solids concentration of about 2.5% and a loading rate of about 20 kg D.S./m²·da (4 lb D.S./ft²·da); this gave final solids concentration of 5.2%. Hathaway and Farrell recently studied the gravity thickening of Al^{+++} and Fe^{+++} primary sludges in bench top tests (5). In agreement with the work of Envirotech, they found that Al^{+++} and Fe^{+++} primary sludges have very low thickening rates. However, dilution of Al^{+++} primary sludges with effluent before thickening, by Hathaway et al., produced a dramatic increase in the thickening rate and increased the thickened solids concentration. The beneficial effect of dilution on Fe^{+++} primary sludges was also substantial. Further, the addition of polymers in the thickening step substantially increased the thickening rate and thickened solids concentration for both the Al^{+++} and Fe^{+++} primary sludges. The preliminary results of pilot-scale, dissolved air flotation thickening tests on unconditioned sludge by Envirotech are presented in Table IX. The effects of level of Al^{+++}, level of Fe^{+++}, and polymer addition to wastewater were not as clear as in gravity thickening. Further, the degree to which the Al^{+++} and Fe^{+++} primary sludges could be thickened differed little, and when these results were compared with those of gravity thickening, it was surprising to see little difference. Hathaway and Farrell in similar dissolved air flotation testing obtained results that were superior to those they obtained with gravity thickening (6). However, they used polyelectrolyte to condition the sludge prior to thickening. Al^{+++} and Fe^{+++} primary sludges were thickened on an average to 6.3 and 5.2% solids concentrations, respectively, when solid loading rates of from 5 to 20 kg D.S/m²·hr (1 to 4 lb D.S./ft²·hr) were employed. As the Al^{+++} or Fe^{+++} concentration in the sludge increased, they noted that the float solids concentration decreased.

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*D.S. = dry solids

A 15 cm (6-inch) Sharples solid-bowl centrifuge was employed by Envirotech to determine the sludges' dewatering characteristics (4). Preliminary data are shown in Table X for a "G x Pool Detention Time" value of 500 g-min (G is the centrifugal force in multiples of force of gravity). During testing, the centrifugal force at mid-depth in the bowl averaged 1990 g's or about 5000 rpm, and the centrifuge's pool volume was 1.556 l (0.411 gal). The poor solids capture is evident for the instances where the sludges were not first conditioned by the addition of polyelectrolyte. However, capture was still on an average 85% better for the unconditioned Fe^{+++} sludges than it was for the unconditioned Al^{+++} sludges. With appropriate polymer conditioning, high level solids capture was obtained for both Al^{+++} and Fe^{+++} primary sludges. Good cake solid concentrations were obtained for all sludges without the use of polymer, although in general the Fe^{+++} sludge cakes were about 26% drier than the Al^{+++} sludge cakes. With polymer conditioning, the cake solids concentration for the Fe^{+++} sludge cakes, however, were on an average 50% drier than the Al^{+++} cakes. Results of pilot-scale vacuum filtration tests are shown in Table XI. In all instances reported in these preliminary test results, the vacuum employed was equivalent to 0.69 kg/cm² (20 in. mercury), cake discharge was good, and solids capture was very high (98-99%). A review of the test results shows that the Al^{+++} primary sludge produced at a low Al^{+++} dose filtered better than the higher dose level sludge. The low dose level Fe^{+++} primary sludge, however, filtered at essentially the same rate as the sludge with a larger amount of Fe^{+++} in it. In comparing the low level Al^{+++} and Fe^{+++} primary sludges, it is noted that the Al^{+++} sludge filtered with a greater production rate than the Fe^{+++} sludge, but that the Fe^{+++} sludge gave a drier cake. The Al^{+++} sludge gave a significantly lower production rate than the Fe^{+++} sludge in the high level salt addition studies, however, and the cake solids for both sludges were not significantly different. An overview of the data readily shows that an increase in either the filter's feed sludge solids concentration or level of lime addition caused greater filter production rates. The production rate could also be increased by decreasing the filter's cycle time. Cake dryness increased with lime addition.

The addition of lime to primary treatment generates another type of upgrading sludge. Investigators at EPA's Blue Plains Pilot Plant (District of Columbia) have conducted tests on the thickening and dewatering properties of lime sludges (6). For a high lime sludge (pH~11.5), it was calculated that with a solids loading of 26.4 kg D.S./m²·hr (5.42 lb D.S./ft²·hr), 12% underflow solids could be obtained. Similarly at a solids loading of 18 kg D.S./m²·hr (3.7 lb D.S./ft²·hr), it was calculated than 20% total solids in the underflow could be obtained. With low lime sludges (pH~10.5), a 3% clarifier underflow solids sludge could be thickened to a 6 to 9% solids concentration at only a loading rate of approximately 9.3 kg D.S./m²·hr (1.9 lb D.S./ft²·hr). The investigators cautioned, however, that these data had not been verified in continuous thickening tests. The low lime sludge could be dewatered on a vacuum filter at a rate of 10 to 15 kg D.S./m²·hr (2 to 3 lb D.S./ft²·hr) and give a 28 to 29% cake solids concentration. The high lime sludge, however, could be dewatered at a rate of 29 to 45 kg D.S./m²·hr (6 to 9 lb D.S./ft²·hr) and give a cake solids concentration of 35 to 36%. Blue Plains does have a low magnesium content wastewater, and the high lime sludge was found to contain only 3 to 4% $Mg(OH)^2$. Mulbarger has discussed in detail the relationship between magnesium in a sludge and a sludge's dewaterability (7).

Van Fleet et al. have reported on chemical sludge handling experiences in Ontario (8). When 90 mg/l of alum and 0.4 mg/l of a polymer were added to wastewater at the 76 m^3/min (29 MGD) West Windsor primary plant for phosphorus removal, the solids content of the primary sludge dropped from 11.5 to 7.6%. Further total solids production increased from 0.10 to 0.216 kg D.S./m^3 of plant flow treated (800 to 1800 lb D.S./MG of plant flow treated). The corresponding vacuum filter yield and filter cake solids content dropped from 55.2 to 28 kg D.S./m^2 hr (11.3 to 5.8 lb D.S./ft^2 hr) and from 31.1 to 19.2% solids, respectively. Sludge conditioning with ferric chloride and lime was more difficult, with chemical costs rising from $3.42 to $10.47 ton (metric) $3.10 to $9.50/ton) of dry solids produced. Somewhat similar experiences occurred at the Little River conventional activated sludge plant in Ontario when 150 mg/l Al+++ were added to the raw waste. However, when 125 mg/l of lime as Ca(OH) instead of Al+++ were added to the Little River Plant's raw waste, sludge treatment improved. The sludge solids concentration and vacuum filter yields went up and chemical conditioning costs per ton of solids processed went down. Sludge production, however, was increased by close to 50%.

SOME POTENTIAL SOLUTIONS

Waste chemical and activated sludges have been shown to be two sludge types not readily handled by conventional technology. This factor sparked the initiation of several research projects reported on here.

LIME STABILIZATION

The addition of lime in sufficient quantity to elevate the pH of a raw sludge to between 12.2 and 12.4 for a lime sludge contact time of 30 min. is an effective, simple, and relatively inexpensive alternative to other sludge stabilization schemes (9). With the lime addition technique just described, the pH of the sludge should remain above 11.0 for better than 2 weeks. Paulsrud and Eikum's results agree with these findings and their determination of the lime doses required to keep different types of sludge at a pH greater than 11.0 for 14 days is shown in Table XII (10). Results of lime stabilization are destruction of pathogenic bacteria (Table XIII), good dewatering on sandbeds, elimination of obnoxious odors, and the possibility of as much as a 50% ammonia-nitrogen reduction (11). Battelle-Northwest has estimated the costs of lime addition to a pH of 12.2 to the costs of lime addition to a pH of 12.2 to 12.4 including all operation and maintenance costs to range from $9/ton (metric) D.S. ($8/ton D.S.) for primary sludges to approximately $17/ton (metric) D.S. ($15/ton D.S.) for biological sludges (9). Lime stabilization has immediate application in situations where a plant through upgrading or because of a digester failure suddenly has large amounts of sludge that require quick stabilization.

AUTOTHERMAL THERMOPHILIC AEROBIC DIGESTION

Past and recent laboratory studies have indicated benefits for the elevation of an aerobic digester's temperature to 40, 50 or 60°C. The rate of volatile solids destruction significantly increases with an increase in temperature. At the higher temperatures, only several days are required for the biodegradation of sludge solids as opposed to a few weeks. In fact, during cold weather a typical aerobic digester may only accomplish 10 to 15% volatile solids destruction in a week.

Recent laboratory, pilot and plant scale studies of the aerobic digestion process have shown that considerable heat is released by the microorganisms during their metabolism of organic sludge solids. Working with oxygen instead of air in a closed plant scale aerobic digester at Speedway, Indiana, and at normal loading rates, 1.28 kg Vs/m^3day (0.08 lb Vs/cu ft-day), the temperature was found to rise to about 33°C and remain near this temperature in year-round operation. The system was essentially independent of the external air temperature. Pilot work at Denver with an open aerobic digester using pure oxygen and sludge loading rates of about 4.81 kg VS/m^3 day (0.3 lb VS/cu ft day) resulted in a temperature rise to near 33°C despite very cold air temperatures. Covered pilot digesters were operated at Tonawanda, New York, at feed sludge loading levels of 8.01 to 9.61 kg VS/m^3day (0.5 to 0.6 lb VS/cu ft-day). These units achieved temperatures near 60°C.

Advantages to be derived from an autothermal aerobic digestion process are a much smaller volume reactor requirement because of the high loading rates and rapid solids destruction. Operation at thermophilic temperatures (45-60°C) will produce a pasteurized sludge suitable for land disposal. Preliminary results indicate that the digested sludge settles and dewaters better than raw sludge and sludge from a conventional aerobic digestion system.

The Los Angeles, California, Hyperion Activated Sludge Treatment Plant routinely reduces 247 metric tons (272 tons) per day of solids to 111 metric tons (122 tons) per day by mesophilic anaerobic digestion. They have recently been experimenting with thermophilic anaerobic digestion. Temperature differentials of ±1.7°C in a day or two upset tank stability, but a successful operational temperature range has been established between 46 and 51°C. Since the particle size of thermophilic sludge is more coarse than the mesophilic sludge, the dewaterability on vacuum filters and centrifuges produces a drier cake and uses less chemicals as verified on pilot and full size equipment. However, filtrate-centrate concentrations from dewatered thermophilic sludge are higher in grease, COD, and heavy metals.

After weighing the additional energy and heat requirements of thermophilic operations against the benefits derived from the dewatering process, results indicate that anaerobic digestion at a thermophilic temperature range can be an important and economic step in the total sludge disposal problem. Los Angeles is currently the only location in the United States utilizing thermophilic anaerobic digestion.

ASH CONDITIONING

In laboratory dewatering tests using sludge incinerator ash as a conditioner, the filter yield of ash-conditioned sludge (ash-free basis) was found proportional to ash dosage and to approximately double at dosage levels of 1.5, 1.7, or 3.1 kg ash/kg sludge solids for waste activated, raw primary, or digested primary sludges, respectively. The moisture content of dewatered ash-conditioned sludge (ash-free basis) generally increased somewhat for all sludges. Interestingly, the filtrate from dewatering of the ash-conditioned sludge was of a high quality (12). The properties of ash that enable it to improve dewatering of sludge include partial solubilization of its metallic constituents, its sorptive capabilities, and the irregular shapes of the particles. In Indianapolis, Indiana, the city recently began using sludge incinerator ash to condition a mixture of primary and activated sludge before dewatering. The dramatic effect of ash addition on the average performance of the plant's rotary vacuum belt filters is shown in Table XIV. Indianapolis succeeded in increasing its filter productivity by as much as 300% and decreasing its cake moisture by as much as 22%. The filtrate quality has also improved, and from a cost viewpoint, the cationic polymer requirement has been reduced by approximately 33%. These data were obtained in late 1977; at that time, the plant was handling approximately 189,569 kg D.S./day (418,000 lb D.S./day) and the ratio of ash to dry sludge solids varied from 0.25 to 0.50. The ash handling facilities required almost no investment and no additional operating cost. The relative location of the ash slurry line to the gravity sludge thickeners provided for easy ash addition, and only a tap, a short feed line and pump needed to be installed (13).

THERMAL CONDITIONING OF SLUDGE

In heat treatment, temperatures of from 149 to 260°C (300 to 500°F) and pressures of 1034 to 2758 kN/m² (150 to 400 psig) are attained for processing periods. The steps usually involved in the process include sludge storage, grinding, preheating, high pressure and temperature reaction, thickening and decanting, auxiliary liquor treatment, off-gas deodorizer and steam. Significant changes in the nature and composition of wastewater sludges result. The effect of heat treatment has been ideally likened to syneresis of the essentially cellular material. These cells contain intracellular gel and extracellular complex dome with equal amounts of carbohydrate and protein. Heat treatment breaks open the cells and releases mainly proteinaceous protoplasm. It also breaks down the protein and complex dome, producing a dark brown liquor consisting of soluble polypeptides, ammonia nitrogen, volatile acids, and carbohydrates. The solid material left behind is mineral matter and cell wall debris.

Dewaterability is usually significantly improved by the solubilizing and hydrolyzing of the smaller and more highly hydrated sludge particles which then end up in the cooking liquor. While analyses of this liquor from domestic wastewater sludges indicates the breakdown products are mostly organic acids, sugars, polysaccharides, amino acids, ammonia, etc., the exact composition

TOP FEED ROTARY VACUUM FILTRATION

The City of Milwaukee, Wisconsin, under an EPA grant, performed a pilot scale study of dewatering waste activated sludge containing Fe+++ salts by top-feed vacuum filtration. The Fe+++ was added into the activated sludge system for phosphorus removal. Gravity thickened Fe+++ activated sludge was conditioned with ferric chloride and filtered on a 1 m (4 ft) diameter, 2 m (6 ft) face vacuum filter in both the bottom-feed and top-feed modes at the Jones Island Plant. The top-feed filter was compared on a side-by-side basis with the large bottom-feed production filters. Production rates to 7.91 kg D.S./m²/hr (1.62 lb D.S./ft²/hr) at 14.5% cake solids were produced in the top feed mode as compared with 6.61 to 7.62 kg D.S./m² hr (1.35 to 1.56 lb D.S./ft² hr) at 11.6 to 16% cake solids for the bottom feed filters. Discharge of filter cake from the top-feed unit was far superior to that from the bottom-feed units (14).

CAPILLARY BELT FILTER PRESSES

A general description of these relatively new sludge dewatering devices was given earlier. While little performance data are available on the devices, EPA partially assisted in development of one unit, a capillary dewatering device which is shown in Fig. 3 and will be described here (15). Conditioned sludge is distributed over the screen longitudinally through a series of openings that create a uniform liquid level. This portion of operation releases free water which drains through the screen. Solids concentration is increased by approximately 10%. After the initial free water release, the screen carrier comes in contact with the capillary belt, which is the unusual feature of the device. The additional dewatering comes from the capillary action of this belt; the capillary dewatering zone is shown in Fig. 4. The carrier screen and sludge continue along the longitudinal plane after capillary dewatering where it is pressed by a single compression roller which extracts additional liquid for a final dehydration. The sludge cake transfers from the belt to the smooth compression roller; it is collected by a doctor blade, falls in clumps onto the screen, and is carried to a discharge chute.

Considerable data were obtained on a pilot plant scale at the Long Road treatment plant near Pittsburgh, Pennsylvania (Table XV). Feed capacities from 10 to 22 kg D.S./m² hr (2 to 4.5 lb D.S./ft² hr) were achieved with cake solids at discharge ranging from 15 to 18% for activated sludge. Machine capacities more than twice these values may be possible. It was found that the device operated without coagulant addition at a penalty to solids capture. With polyelectrolyte addition of 5 kg/ton (metric) D.S. (10 lb/ton D.S.) at an equivalent cost of $4.41/ton (metric) D.S. ($4/ton D.S.), sludge solids capture of 95% was obtained when the machine was operated at 9.8 kg D.S./m² hr (2.0 lb D.S./ft² hr). At higher machine capacities, i.e., 20 kg D.S./m² hr (4.0 lb D.S./ft² hr) or higher, the system operated more economically with use of ferric chloride conditioner. Overall machine operation depended on chemical addition, sludge solids loading, and screen mesh size. Total cost estimates for capillary dewatering ranged from $21.34 to $43.74/ton (metric) D.S. ($19.36 to $39.67/ton D.S.) processed in plants of the 5 to 11 m³/min (2 to 4 MGD) size (15).

PRESSURE FILTRATION OF SLUDGE

Experience in the United States with pressure filtration of municipal sludges has been limited. A recent installation of pressure filtration was made at the Cedar Rapids, Iowa, 75.7 m³/min (28.8 MGD) two-stage trickling filter plant to dewater an anaerobically digested mixed primary and secondary sludge. EPA participated in the evaluation of its performance. A combination of recycled ash and chemicals is used before dewatering to condition the 25,397 kg (56,000 lb dry basis) of digested sludge per day (16). Sludge cake discharges from the filter with a cake solids content in the range of 62 to 64%, and the cake's appearance is dense, dry, and textured. Although the Cedar Rapids plant normally dewaters digested sludge, full-scale tests have also been successfully run on raw primary sludge. The costs at Cedar Rapids are related to the concentration of feed solids. At 4.5% solids, the average total capital and operating costs were $29.58/ton (metric) D.S. ($26.83/ton D.S.), and at 6.5% solids, $20.07/ton (metric) D.S. ($18.20/ton D.S.). Incineration has normally been achieved without the use of supplemental fuel.

The Kenosha, Wisconsin, activated sludge wastewater treatment plant recently installed two Edwards and Jones filter presses to dewater its digested sludge. Performance requirements for the presses are that they process a 3 to 6% digested sludge working 16 hours a day, 5 days a week, and remove approximately 9,525 kg (21,000 lb) of dry solids per day. Sludge is fed into the press at a maximum pressure of 7.03 kg/cm² (100 psi), and a complete cycle takes 3 to 5 hours. Each press produces 3 cm (1 inch) thick cakes of about a 40% solids concentration. Sludge conditioning requires 5 to 10% ferric chloride and 12 to 15% lime on a dry weight basis (17).

PYROLYSIS

Pyrolysis is the destructive distillation of organic materials under pressure and heat in the absence of oxygen. Through the pyrolysis process, the organic portions of waste are reformed into lower molecular weight compounds. These compounds can be in the form of a combustible gas, tar and oil, and a solid "char" which also has an appreciable heating value. Generally, the "pyrolyzing" process is carried out in an externally heated closed reactor chamber. Process temperatures can be as low as 500°C (932°F) or in excess of 900°C (1652°F) at atmospheric pressures. At the lower temperatures the reaction product is predominantly solid and at higher temperatures gas is more prevalent. The volatile gases can be siphoned off and used to heat the reaction chamber. The process can be thermally self-sustaining providing the heating value of the waste is high enough.

Since the combustion of sludge normally requires the use of auxiliary fuel, EPA intends to investigate at two sites on a plant scale the copyrolysis of sludge and solid wastes mixtures. At one site the production of a useful gas will be emphasized while at the other, products other than gas will be emphasized.

PURETEC WET OXIDATION OF DIGESTED SLUDGE

Philadelphia will shortly demonstrate the use of this process at their Northeast Plant. The unit will process daily 15 tons of dry sludge solids, which is equivalent to a wastewater flow of 681,000 m³/day. In the process, sludge is brought to a pH of about 3 with sulfuric acid, heated to 232°C and contacted with air at a pressure of about 4,137 kN/m². The sludge flows through a series of compartments, each equipped with an agitator, in a single horizontal cylindrical vessel. A gaseous and a liquid stream are removed. Benefits anticipated with this process include: 75 to 85% COD destruction, the generation of surplus thermal energy, the conversion of nitrogen compounds to recoverable ammonia and the rendering of metals extractable. The predominant organic compound in the resultant solution is acetic acid.

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INORGANIC SUSPENDED SLUDGE DEWATERING

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It is known that a great mass of multicomponent sludge suspension (with humidity 98-99%) is collected on the industrial treatment facilities. These colloid systems include negatively and positively charged particles which settle down badly. Such sludges must be deposited out of the community region in such ground from which they can not get into the aquiferous layers. The very procedure is very expensive in addition to the difficulty to find the needed geological structure of the ground throughout the country territory. It forces to obtain the maximum concentrated sludge of small volume and with the simple procedure of depositing.

The methods of settling and mechanical dewatering with the help of filters and centrifuges are used for thickening with prior treatment by chemical reagents. It results in humidity lowering up to 80-90%.

In the last period the electrical method of water removal is becoming spread especially in some technological processes. In order to prove the usefulness of the electrical method in waste water sludge treatment the scientists of the Leningrad Institute of Civil Engineers (LISI) have carried out some experimental tests. Two groups of mostly characteristic sludges were chosen. Those were the sludges from the recycling water systems and from some technological waste waters of several industrial plants. The first group consists of flocculent sludges of metal hydroxides as those after the galvanic work. The second one consists of more concentrated silicate-oxide dispersion as those from the ceramic, refractory and abrasive industries. As far as the concentrating process of dispersion systems depends on their physical-chemical properties the following parameters were investigated: chemical composition of solid and liquid phases, electrical conductivity, acidity, dispersion degree, stability, ζ-potential and the coagulants and flocculants influence.

The average data state that the basic properties of heterogeneous, multidisperse, multicomponent systems are characterized with the solid phase from 1.03 to 10%, alkalinity from 0.6 to 345ppm, volume weight from 1.00 to 1.07g/cm³ and the particle size from 1 to 30 mm with the pick on the distribution curve in the range 2-5 mm. The chemical structure of the investigated sludge was controlled by spectrochemical analyses.

The dispersion system mainly consisted of the metal oxides: silicon 2.9-55.5%, aluminium 2.25-11.9%, manganese 1.97-22.9%, magnesium 0.2-7.3%, chrome 0.65-12.14% and small content of cadmium and copper. The compactness of the solid phase was 1.98-2.91 g/cm³ and that of the liquid phase was from 1.00 to 1.09g. The electrical conductivity was from 6.2·10⁻⁵ to 1.9·10⁻² 1/om·cm.

The refractory suspension had relatively high aggregative and kinetic stability in the wide range of solid phase concentration 0.5-10% weight. The value of ζ-potential is in the range -10/-30mv with electrical conductivity of liquid phase 10⁻⁵-10⁻² om⁻¹·cm⁻¹.

The injection of aluminium sulphate in refractory suspension lead to the distortion of its stability. The points of coagulant dose 40÷75mg/l were those at which the suspension started to settle as non stable one with the particle enlargement from 2 to 30 mm. Both ζ-potential and system stability lowering is the result of the increasing of anion content and compression of double ion layer. The particle recharge had not been observed (Fig. 1).

The injection of polyacrylamide into the refractory suspension as a flocculant from 0.1 to 25 mg/l lead to the particle settling acceleration and to the particle enlargement from 100 to 500 mm. The reduction of ζ-potential and the increasing of sludge volume were noted as well. The similar influence of flocculant on hydroxide sludge was observed when the content of polyacrylamide was increased up to 250 mg/l.

Thus during the investigation of physical-chemical sludge properties the usage of flocculants was shown to be the most proper way in case of separation followed by compression in hydroxide systems. It is mostly effective to combine the coagulant and the flocculant for better concentration of solid phase, particular, for the refractory suspension.

The process of dispersive particle interactions when the electrical field is used is known to be the result of double ion layer deformation, dipol-dipole interaction. Under this influence the dispersive particles become closer to each other and form the convertable or non-convertable aggregates, depending on the summary curve shape of the potential energy of particle interaction. Using the theoretical explanation of the influence of electrical field on suspension system it is possible to determine parameters of the electrical treatment process for some certain objects of the investigation. This is achieved with the help of the analytical methods.

The behaviour of the chosen systems in the electric field had been checked on the devices of types ВСА-111 or УИП-1, consisting of the source of stable voltage and a working chamber. The range of voltage was E=5-150 v/cm. As the tests showed the dispersion particles in the metastable hydroxide sludge started moving, coagulating and aggregating under the influence of the electrical field. This process was characterized by the differential distribution curves accordingly to the particle size up to the moment of the electrical field influence and after it (correspondently 3-5 mm and 600-700 mm) at E=10-300 v/cm. By the experiment it was proved that the sludge compression is practically finished in five minutes after the moment of the electrical field laying on. At the same time the electrical current that flowed through the system was increasing to some stable value. Changing of physical-chemical properties of the system was observed along with the particle aggregation (Fig. 2). If the change of limit settling volume is taken as a criteria to evaluate the system stability in case of electrical field influence within the range E = 5-40 v/cm, one can notice that the minimum dispersion stability is corresponding to the maximum limit settling volume, E=10-30 v/cm for positively and negatively charged systems. Within this voltage range the typical changing of ζ-potential was observed. But it can not be explained up to now. The flocculent, chemically formed sludge results from the electrical treatment, with less resistance to filtration. The concentration of the dispersion system, prior being aggregated in the electrical field, may be done either mechanically (Table 1) or with further electrodewatering with the simultaneous filtrate removal under the gravity field.

Table 1

Influence of the electrical treatment of systems
at E optimal on the vacuum filtration parameters
(vacuum - 500 mm of mercury column;
filtration cycle - 2 minutes)

Type of sludges		Hydrodynamic specific resistance $\times 10^{8}$ cm/g		Efficiency of vacuum filter kg/m² hour	
		before electrical treatment	after electric treatment	before electric treatment	after electric treatment
Sludge after galvanic work*	1	72.2	44.1	6.7	14.6
	2	28.4	11.5	10.5	26.4
Sludge from electrode shops		64.5	16.0	6.07	12.9

*Different industrial samples of hydroxide sludges with equal concentration of the solid phase were taken for testing.

It was proved by the tests that the dewatering process of studied systems was correspondently increasing for a number of electrodes: stainless steel < coal < aluminium < brass. 62% humidity was achieved with the usage of brass and aluminium electrodes.

The refractory suspensions are more aggregatively stable (Fig. 3). The noncorrectable coagulation was evaluated on the base of the suspension transparency. It changes jumplike at the critical voltage of field. The loss of the system stability under the influence of the electrical field in range E from 10 to 150 v/cm is accompanied by lowering ζ-potential without the meaningful changing of the electrical conductivity of liquid phase. These changings in the system stability can be explained by Deriagin-Landau-Ferwey-Overbeck theory, the polarizational interaction of separate particles being taken into consideration. The common usage of reagental and electrical methods is especially reasonable for the separational processes. The electrical treatment of the refractory suspensions gives the possibility to lower E from 125 v/cm to 50 v/cm when 10-25 mg/l of aluminium sulphate is injected in these suspensions (the limiting dose 40-75 mg/l). The application of the electrical field results in more intensive aggregation, because the forces of dipole-dipole interaction are proportional to the third degree of radius of particle interaction. Therefore the injection of the coagulant in small doses causes the spontaneous process of suspension coagulation. These doses change the particle dispersability unconsiderably and have no on the system stability with the following usage of the electrical field. To increase the concentration of the solid phase is necessary to carry out the electrical treatment of the refractory suspensions in two stages. It allows to get the weight concentration of the solid phase 35-40% depending on the field voltage.

On the base of the past experiments the technological scheme of the sludge concentration with the usage of the electrical field is proposed (Fig. 4). It has been proved that the dewatering of sludge with the help of the electrical treatment is economically better than that with the mechanical method. For example, the costs for the hydroxide sludge dewatering (one plant is taken) are 39,000 roubles when the vacuum-filtration costs are 20000 roubles with the usage of the electrical field.

Subscription to Figures

I. S. Lavrov, N. F. Fedorov, V. N. Ponomareva
"Inorganic suspension sludge dewatering."

Fig. 1. Dependence of the specific electrical conductivity (1), ζ-potential (2), limiting sedimentation volume (3), and light transparency (4), of the refractory suspension on the content of aluminium sulphate.

Fig. 2. Dependence of ζ-potential (1,1), limiting sedimentation volume (2,2), specific resistance (3) of the hydroxide suspension on the field voltage; 1,2,3 - for the initial suspension; 1, 2 - for the suspension after washing.

Fig. 3. Dependence of the specific electrical conductivity (1), ζ-potential (2), limiting sedimentation volume (3) and light transparency (4) of the refractory suspension on the field voltage and aluminium sulphate at E=100v/cm (1,2,3).

Fig. 4. The technological scheme of the sludge concentration with the usage of the electrical field.
1. electrocoagulator
2. vacuumfilter
3. electrical dewatering machine
4. the source of constant current
— unstable suspension
--- stable suspension

DEWATERING OF SEWAGE SLUDGE BY MEANS OF CENTRIFUGES

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The method of sewage sludge dewatering by means of the continuously operating centrifuge with dewatered sludge scroll discharge has become rather popular lately.

The advantages of the sludge centrifugation method compared to the conventional methods widely used in this country, such as drying in beds or mechanical dewatering in rotating vacuum filters are as follows.

The units are compact, mechanical dewatering can be performed without addition of chemicals, dewatered transportable sludge of low moisture content is produced under normal sanitary conditions.

The scroll discharge centrifuge is notable for its high centrifugal force (i), compactness, continuous initial sludge supply and product discharge and relatively low energy consumption per 1 m^3 of treated sludge.

The main scroll centrifuge performance parameters are sludge dry residue detention efficiency, centrifuge capacity and cake moisture content.

Table 1 illustrates centrifuge performance results obtained on different types of sewage sludge, no chemicals were added.

TABLE 1

Sludge dry residue detention efficiency and cake moisture content with the sludge being dewatered by centrifugation

Type of sludge	Dry residue detention efficiency %	cake moisture content %
raw or digested primary	45-65	65-75
digested primary and activated sludge mixture	25-40	65-75
raw activated sludge of the following ash content		
28-35%	10-15	70-80
35-42%	15-25	65-75

Actual value of sludge dry residue detention efficiency was calculated by the following formula

where Cin, Ck and Ccp are dry residue, cake and centrate concentrations, respectively.

Centrifuge performance parameters depend on the bowl geometric size and centrifuge operating conditions, the bowl speed, the discharge cylinder diameter and the feed pipe position, and also on the initial sludge properties, such as the solid phase density and dispersion composition, bound water quantity, the liquid phase viscosity and some other properties, the dependence of separate parameters for different types of sludges differing considerably. Thus the centrifuge capacity increase during raw sludge processing results in a slight cake moisture content increase and vice versa in humidity decrease in processing activated sludge.

The investigations of dispersion composition showed that about 90% activated sludge solids are of 0.15 mm size, whereas only 45% of such solids are contained in raw sludge, therefore dry substance detention efficiency is 30-40% higher than that of activated sludge.

Industrial effluent influx into municipal aeration stations, sewage flow and composition fluctuation, sewage treatment station arrangement and operating conditions variations in separate units cause change in sludge physico-chemical properties and consequently in the centrifuge performance efficiency.

Chemical conditioning and heat treatment promote centrifuge performance efficiency increase. However, preconditioning being very expensive, much attention was given to centrifugation without chemical conditioning. In connection with high suspended solids loss with centrate there were developed several technological treatment schemes:

1) utilization of centrifugated excessive activated sludge centrate as return sludge;

2) centrate discharge to the preliminary settling tanks after raw and digested sludge centrifugation;

3) combined aerobic and anaerobic digestion of centrate activated sludge mixture;

4) digested sludge centrate drying in beds.

Activated sludge centrifugation yields the greatest amount of suspended solids in the resulting centrate. Meanwhile the amount of dry residue after centrifugation exceeds that of the dry residue formed in the activated sludge growth process in the course of sewage treatment.

Hence there has been offered a method by which secondary activated sludge is centrifugated, intestinal worms in the resulting cake are destroyed and the centrate is used for biological sewage treatment instead f return activated sludge or in mixture with the latter(3).

The method was laboratory tested in the models of aerotanks: the centrate produced in the process of secondary activated sludge centrifugation (the sludge was taken from Lublino aeration station) was used in one of the models, and in the other return activated sludge. The experiments were conducted on contact basis and the models also worked as aerator-clarifier units. Sludge concentration in the aerotanks was from 0.80 to 3.79 g/l. Air consumption was measured by means of rotameter and made up from 15 to 35 m^3/m^3 of sewage.

Comparison of return sludge and centrate sewage treatment results indicated that centrate can be used for sewage water treatment instead of return activated sludge centrate. Sewage treatment quality is competitive with that of return activated sludge sewage treatment. At contact time from 1 to 24 hours BOD_5 decreased to 73.5 mg/l when sewage was centrate treated, and to 65.3 mg/l when return activated sludge was utilized.

In both cases the amount of suspended solids reduced to 55.8 mg/l. Return activated sludge index fluctuated from 65 to 118, and that of centrate from 80 to 127.

The amount of pollutant, oxidized in the aerotanks where return activated sludge was used fluctuated from 46 to 172 mg BOD_5/g of sludge dry residue depending on the initial BOD_5, duration and sludge dose, and from 44 to 158 mg BOD_5/g of sludge dry residue when centrate was used. Since laboratory work is not sufficient when testing aerotanks continuously utilizing centrate as return activated sludge, the experiments were conducted in 1.5-2 thousand m^3/day treatment plants.

These experiments results are listed in table 2.

Aeration duration varied from 8 to 10 hours. Aeration intensity was maintained continuously at 4.3m^3/m^2/hour. Activated sludge growth at 4.5 g/l sludge concentration averaged 180 g/l of sewage or 4.15 kg/hour. Centrifuge capacity being 4m^3/hour it caught 8.0 kg/hour of sludge dry residue on the average. It took $\frac{4.15 \cdot 24}{8.0}$ = 12.4 hours/day of centrifugation to remove all the surplus sludge from the system, only 11.1% of the secondary activated sludge being fed to the centrifuge.

According to table 2, the results of the two compared sewage treatment schemes were roughly equal. The treated sewage BOD_5 varied from 4.6 mg/l in summer time to 20.6 mg/l in winter time, the suspended solids amount fluctuating from 7.3 mg/l to 25 mg/l respectively.

Thus centrifugation for the purpose of surplus activated sludge separation and centrate utilization for sewage treatment did not deteriorate the treated sewage quality as compared to the conventional scheme of treatment.

Centrate addition to circulating sludge in aerotanks results in the surplus activated sludge treatment scheme simplification, since there is no more need in sludge thickening, digesting and drying in beds. All the enumerated operations are replaced by centrifugation of a portion of taken directly from secondary clarifiers activated sludge. This sludge amount is determined on the basis of its growth and operating dose.

When primary sludges are centrifugated, the simplest method of centrate treatment consists in its discharge to preliminary settling tanks(3).

Centrate discharge to preliminary settling tanks results in the settled sewage SS concentration increase in influent and clarified sewage and also in the increase of the amount of sludge formed in clarifiers. SS concentration in the influent sewage with continuous and multiple centrate addition to the latter can be calculated by the formula mentioned below, provided the settled sewage concentration increases in proportion to the initial sewage concentration increase:

$$Cn = C_1 + \frac{C_1 m (1-K)}{1-m(1-K)}$$

Where Cn – suspended solids concentration in sewage-centrate mixture,
C_1 – SS concentration in influent sewage,
m – SS carrying out with centrate coefficient,
K – SS carrying out of clarifiers coefficient.

In the cases when SS carrying out of preliminary settling tanks increase is inadmissible, i.e. condition KCn=const preservation is indispensable, influent sewage plus centrate mixture concentration can be calculated by the following formula:

$$C'n = C_1 + \frac{C_1 m (1-K)}{1-m}$$

Having substituted values $C_1 = 1$, $K = 0.6$ and $m = 0.525$ in formulae (2) and (3), we receive:

$$Cn^{(2)} = 1.26; \quad Cn^{(3)} = 1.44$$

Experiments in Lianozovo results showed, that settling duration should not be prolonged for the first condition realization, i.e. when K=const (fig. 1). Nevertheless SS amount in settled sewage increase by 15.30%, the latter circumstance should be taken into account when digesting in biological treatment units. Raw sludge centrate

TABLE 2

[illegible]

[illegible]	[illegible]		[illegible]		[illegible]			
					[illegible]		[illegible]	
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

plus unthickened surplus activated sludge mineralized mixture centrifugation is of considerable interest.

The centrate volume to surplus activated sludge volume ratio corresponded to their real ratio in treatment plants which equalled 1:10. Air consumption made up 2.3 m^3/m^3/hour.

The mixture ash-free substance decomposition dependence on aeration duration is shown in Fig. 7.

Maximum ash-free substance composition in the course of 8-10 days reached 35-40%. Extension of aeration duration over 10 days did not cause any considerable ash-free substance decomposition rise.

Mineralized mixed liquor taken from the aerotank-stabilizer settles better than initial sludge-centrate mixture. The mineralized mixture dry substance detention by centrifugation efficiency is 1.5-2 times more than that of initial mixture dry substance detention.

Comparison of digested sludge and centrate drying efficiency in the laboratory drying beds with an artificial slag-sand foundation and in the half-size beds with natural foundation and drainage showed, that in 12 days of 6.5% concentration sludge drying, the sludge bed thickness reduced from 35 to 24 and that of centrate from 35 to 8, the dried centrate being of 10.9% concentration and pasty, and the digested sludge - of 9.3% concentration and fluid.

During 3 summer months there were carried out two digested sludge fillings and a 0.7 m bed was dried in one half-size bed. During this very period in the other drying bed four centrate fillings were realized and a 1.4 m bed was dried.

By the end of this period the initial sludge drying bed drainage was clogged up with sludge solids and practically did not function, whereas in the bed, designed for centrate drying, the dried sludge cracked, which resulted in subsequent satisfactory drainage functioning.

Sludge dry substance concentration decrease after sludge centrifugation, and more rapid centrate thickening in drying beds indicate, that digested sludge preliminary centrifugation results in drying beds area reducing by 2-3 times.

Chemicals pretreatment of sludge before centrifugation promotes centrate treatment schemes simplification. High molecular cation flocculants are the most efficient ones for this purpose; by means of some of them 200-500 mg/l SS containing centrate can be produced; the latter does not need any special treatment.

Chemical agents application in centrifugation and the choice of centrate treatment scheme are determined by techno-economical calculation.

CONCLUSION

Sewage sludge mechanical dewatering by means of solid-bowl scroll centrifuges has a number of advantages in comparison with other sludge treatment methods. The method is particularly useful in low capacity - to 50000 m^3/day plants; sludge dewatering without chemical treatment is the principal advantage of the method.

There are worked out several schemes of centrate treatment since large amounts of SS are carried out with centrate.

The centrifuges design perfection and flocculants application, simplifying centrate treatment schemes promote the sphere of centrifuges application expansion.

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THERMAL DRYING OF DEWATERED SEWAGE SLUDGE

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Mechanically dewatered sewage sludge large volume, high moisture content and pollution with pathogenic microorganisms and intestinal worms ova make it necessary to process sludges.

Due to high organic substance content, sludges can be utilized as fertilizers or fuel. In both cases thermal drying is the most expedient method of sludge treatment. Thermally dried sludge presents a disinfected, dry, loose, granulated or powdery produce, its weight and volume being considerably reduced. Drying of mechanically dewatered sludges presents a problem on account of their pasty condition and high adhesion capacity.

To dry mechanically dewatered sludges continuous convective dryers: rotating, belt, loop and pipe-dryers are used.

In most cases a 500-800°C furnace gas is used as a drying agent. Dryed sludge presents a loose, powdery or grainy substance with a moisture content of 5-40%. Rotating dryers have relatively high capacity of a single unit but low moisture removal (60 kg/m^3/hour), the latter circumstance causing the units big sizes, and high weight resulting in gross capital costs, and in the extension of sludge thermal drying shops construction terms. Rotating dryers are also characterized by large fuel quantity consumption. Belt and loop dryers have similar drawbacks, furthermore, they cannot be successfully automated.

Pneumatic pipe-dryers with mechanical grinders, popular in the USA and some other countries, are the most effective ones of the dryers employed abroad. Their drawbacks are units big hight and the availability of moving parts in the high temperature zone.

The analysis of the methods and apparatus used to dry dewatered sludge and other pasty material indicate that the creation of a special apparatus on the basis of modern convective drying methods with regard for sludges individual properties is expedient.

In recent years an all-round investigation of thermal drying was carried out by the Municipal Water Supply, Water and Sewage Treatment Research Institute of the Academy of Municipal Economy. Sludge drying kinetics was studied by means of laboratory hydrometer, used to fix sewage mass variations in the process of convective drying.

The results indicated that dewatered sludges have similar drying rate curves.

Drying of sludges is going on at constant (1st period) and falling rate (the second period). In the second period the drying rate stalls on a complex dependence, drying rate curve including three sections: linear, convex and concave. The obtained results analysis indicates that the moisture in sewage sludges, evaporated by means of vacuum-filters or centrifuges, is mainly bound with capillary and adsorption forces. Capillary moisture removal in the second period (p. 3) is accompanied by the evaporation zone deepening, a dry thickening crust being formed on the sludge surface.

The great bulk of moisture is removed from sludges in the first period and in the bordering upon it linear section of the second period.

According to the theory, rigid drying regimes application in these sections is quite efficient, such regimes securing high intensity of external heat-and mass-exchange. To prevent sludge superheating and the thermal decay of its organic substance of further heating it is necessary to decrease the drying agent temperature and rate, simultaneously increasing the sludge-heat-carrier contact time, thus passing on to a milder drying regime. A productive counterjets method used to dry mechanically dewatered sludges efficiently intensifies the process. The process going on in counterjets, percussive fusion of two oncoming axial-symmetric jets of suspension of sludge in gas takes place. In the zone of jets collision there arises a [illegible] oscillatory movement from one jet to the other, thus increasing the material concentration in the unit, besides the suspension of sludge in gas is considerably turbulized. One of advantages of the method is the utilization of gases high velocity, limited only with the material grinding condition and the housing pipes walls wear, in the latter the suspension of sludge in gas oncoming movement takes place.

Due to the high gas velocity, the phases have sufficiently high relative velocity, material transportation about the unit is improved and also the material dispersion is provided.

To ensure the required variable drying regime there is offered an original method, consisting in consecutive hot gases sludge handling in the counterjet region and disgushing by means of a portion of dried sludge return for drying; the scheme securing the process intensification by the material concentration increase, the material temperature levelling up and the amelioration of its feeding into the unit.

Besides a portion of the dried sludge return provides the regulation of the produce humidity and granulometric composition. According to the offered method the mechanically dewatered sludge drying is carried out in the counterjet dryers. Their principal elements are as follows (fig. 2): 1) a drying chamber, made of two horizontal boosting pipes coaxially fit in the vertical connecting pneumatic pipe; 2) centrifugal air-passing separator. Combustors of aircraft gas-turbine motors having worked off their flying life are used to produce the drying agent. Natural gas or kerosene are utilized as fuel.

For thermally dried sludge or mazut utilization there are developed special chamber; sludge thermal drying being carried out, fuel is required only for warming up and brightening of the unit.

The counterjet dryer operates in the following way. The sludge is fed into the dryer through the receiving ports of the boosting pipes (1). The 600-800°C fuel gas having the velocity of 100-400 m/sec is fed into the dryer from the combustors (3) through the nozzles (2). The indicated velocity is provided by the compressed air (0.11-0.15 MPa-Mega Paskal) feeding into the combustors. To provide the required temperature and combustion of the gas, produced by fuel combusting, the air is fed into the combustors at a quantity of 4.5 normal m^3/kg of the evaporated moisture. The humid sludge, fed to the nozzles shears, is caught up and comminuted with the hot gas and moved in the two oncoming jets. When the streams are collided in the center of the dryer, supplementary sludge dispersion and its intensive drying take place. The sludge dried solids of inadequate humidity and coarseness are returned to be dried again through the pipe (7) after they are classified in the separator (8).

The waste gas, having passed through the system of suction and purification are released in the atmosphere. The produce is transported from the separator to the bunker (10).

The counterjet dryers are notable for a high volumetric stress on evaporated moisture, reaching 700-1000 kg/cm^3/hour, and a low specific heat consumption per process 3.4-3.8 MJ/kg of evaporated moisture. The waste gas temperature does not exceed 100-130°C at the dried sludge moisture content of 30-45% and less.

The dryers are compact, simple to manufacture and operate. The dryer is fully automated.

As a result of the investigation carried out in the laboratory and full-scale counterjet dryers there was offered a generalized method estimation of units for different process regimes.

The main unit estimation parameters are its diameter and the length of the active zone of the drying chamber boosting pipes. The boosting pipes diameter is determined on the basis of the required dryer capacity according to the estimated volume of gas and its accepted velocity and is checked up by means of a criterion heat exchange in oncoming jets equation, formulated by the authors: $Nu = 1.9\,Re^{0.5}$.

The boosting pipes active zone length is accepted to be equal to the doubled value of the maximum solids handover into the oncoming jets and is calculated by the empirical formula:

$$l_a = 2\left(12{,}6 - 2{,}85\frac{H}{D}\right)10^{-4}\,Re\,d_a\,\frac{\rho_s}{\rho}$$

By way of changing boosting pipes diameter and length when utilizing the appropriate separator size, chosen according to gas consumption, the dryers capacity variation in a wide range can be produced. Presently, the counterjet dryers are envisaged in a number of municipal sewage treatment plants projects. One such 150,000 m^3/day unit has been operating at Ochakovo-Zuevo aeration station since 1973.

The drying unit is located at the sludge vacuum filtration shop, taking up about 15 m^2 area; the unit hight is 10 m. The unit dries up to 120 t/day of vacuum-filter dewatered raw sludge. Capacity to the evaporated moisture equals 2.2-3.3 t/hour. In the process of drying the sludge humidity reduces from 75-80% to 35-40%. Fuel /natural gas/ and air consumption per 1 kg of evaporated moisture equals 0.090-0.100 normal m^3 and 3.7-5.0 normal m^3, respectively.

The dried sludge presents a loose granulous product, the size being predominently 1-3 mm.

Due to the presence of nitrogen, phosphorus, calcium, potassium, boron, cobalt, manganese, copper, sodium, zink, etc, the dried sludge is successfully used as an organo-mineral fertilizer.

The counterjet dryer utilization instead of the rotating dryer at Ochakovo-Zuevo aeration station resulted in 150,000 roub capital costs reducing, i.e. by 3-4 times; operating costs reduced by 15%.

Counterjet dryers were also tested on different industrial effluents. One such dryer has been tested at Baikalsky cellulose plant; it was used to dry lignin sludge. The dried sludge was incinerated in the cyclone furnace.

The counterjet dryer is expedient to be widely utilized at treatment plants due to their high reliability and simplicity, satisfactory operating figures and low capital and operating costs.

The counterjet dryers are recommended to be used at 40000 to 1 000 000 m^3/day aeration stations.

DESIGNATIONS

Nu - Nusselt criterion (heat exchanging)
Re - Reinold criterion
d_T - principal sludge solids size
la - the active zone length, m
D - boosting pipes diameter, m
H - The distance between the boosting pipes open ends
ρ_T - volume density of the dried sludge particles, kg/m^3
ρ - gas density at the mean temperature values in the boosting pipes, kg/m^3

CONCLUSION

Counterjet dryers are the most efficient and economic apparatus for the thermal drying and dewatering of mechanically dewatered sewage sludge. The dried sludge is expedient to be utilized as organo-mineral fertilizer.

AEROBIC STABILIZATION OF ACTIVATED SLUDGE

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Sludge treatment is one of the most labour-consuming and expensive parts of the general waste water purification system. Technological schemes of sludge treatment are notable for being complicated and multiform. Stabilization of organic sludges is an important link in the technological chain of their treatment, which results, on the one hand, in the reduction of sludge mass and, on the other hand, in creating satisfactory sanitary conditions on subsequent stages of their treatment.

The aerobic stabilization process carries out in conventional aeration tanks, hereafter they will be referred to as stabilization tanks. Two main technological schemes of the stabilization process - a conventional one (scheme I) and a scheme with recycling involved (scheme II) are shown in Fig. 1.

Being an alternative to anaerobic stabilization, that is to digestion, aerobic stabilization favourably differs from it due to less capital costs it requires and due to its simplicity and reliability in operation.

This paper reflects the results of investigations into the main regularities of the excess activated sludge aerobic stabilization. Degradation of biological mass of activated sludge takes place as a result of stabilization. Kinetics of degradation has been studied by many authors. The results of their studies can be summarized in the following basic points.

1. The whole organic matter of the activated sludge can be relatively divided into two parts: an inert part, Si, which remains unchangeable in the course of stabilization and an active part, Sa, which is subjected to degradation. Hence, the degradation value cannot exceed a certain value A called degradation limit and defined by the equation

$$A = \frac{Sa_0}{Sa_0 + Si} = \frac{Sa_0}{S_0}$$

where S_0 and Sa_0 are respectively values of total quantity of activated sludge and of the active part of activated sludge biological mass at zero time.

The degradation value a_t at time of t is defined by the equation

$$a_t = \frac{S_0 - S_t}{S_0}$$

where S_t is the quantity of activated sludge biological mass at time of t. It is apparent that a_t is always less than A.

2. The active part degradation rate is described by the first-order equation, where k is the degradation rate constant:

$$\frac{dSa_t}{dt} = -k\,Sa_t$$

The oxygen uptake rate in the stabilization process is proportional to the biological mass degradation rate with the stoichiometric coefficient of ν:

$$\frac{dO_t}{dt} = -\nu\,\frac{dSa_t}{dt}$$

where O_t is quantity of oxygen consumed by the activated sludge by a period of time t.

Specific quantity of oxygen $g = \frac{O}{S_0}$, i.e. the quantity of oxygen needed for stabilization of a unit of the activated sludge biological mass, is defined by the equation

$$g = \nu\,\frac{S_0 - S_t}{S_0} = \nu a_t$$

From the engineering point of view the required time of stabilization, t, and the specific oxygen uptake, g, are obviously the basic design parameters.

With the structure of flow in view, the equation for the required detention time may be derived on the basis of Equations 1 - 4:

for a complete mixing reactor $t_{cm} = \frac{a_t}{(A - a_t)k}$

for a plug flow reactor $t_{pf} = \frac{\ln[A/(A - a_t)]}{k}$

for a multi-cell reactor $t_{mc} = \frac{n}{k}\left(\sqrt[n]{\frac{A}{(A - a_t)k}} - 1\right)$

where n is the number of cells.

It follows from Equations 6-8 that the value t is defined in the first place by the values A and b, i.e. the constants of the process, and in the second place by the degradation value a_1.

It is known from literature that A and b are not considered strict constants, but depend on a number of factors hereafter named variables, these dependences being unknown for the most part. As for the value a_1, it follows from Equations 7-9 that if $a_1 \to A$, then $t \to \infty$. It is obvious, that we should choose a minimum permissible value of a_1 or, to put the other way round, a stability criterion. At present the uniform stability criterion is not available in the Soviet and foreign practice.

Thus in order to obtain the needed calculation equations for definition of values t and g it is necessary firstly to find out functional dependences between values A and b and the variables and secondly to choose the stability criterion.

The investigations were conducted in the bench-scale installations, activated sludge involved was grown on synthetic substrates. Real sludges of municipal and industrial waste water were also studied in the experiment. In all tests the biological mass of activated sludge was measured both as the organic matter of mixed liquor (MLVSS) and as COD of mixed liquor, the former defined as the losses during the incineration of mixed liquor.

The regressive analyses determined that kinetics of the biological mass degradation process expressed in mg/l of MLVSS and COD is adequately described by the first-order equation. Hence, (see Equations 6-8) in order to obtain the same value a_1 the time needed for stabilization in the plug-flow reactor will be much less that in the complete mixing reactor. The construction of stabilization tanks being similar to that of the conventional aeration tanks which are complete mixing tanks in case of a long period of aeration, their sectioning by means of tight cut-cross baffles provided with orifices is considered to be necessary.

The investigations into kinetics of oxygen uptake in the process of aerobic stabilization carried out by using a dissolved oxygen analyser showed that the quantity of oxygen consumed by activated sludge over a certain period of time is equal to the COD reduction value over the same period of time. Kinetics of the mixed liquor COD reduction, as mentioned above, is described by the equation of the first-order reaction. So we obtain a simple and reliable method of experimental determination of oxygen quantity demanded for stabilization of various kinds of activated sludges as well as any organic sludges.

Composition of waste water, sludge age, temperature, both sludge and dissolved oxygen concentrations were chosen as variables capable of affecting the values A and b.

It was experimentally determined that neither sludge concentration (within ranges investigated from 7.5 to 30 g/l) nor oxygen concentration (within ranges investigated from 1.0 to 8.5 mg/l) affect the constants of the process.

Experimental studies of the temperature effect upon these values showed that within the investigated range from 5 to 30°C the value A didn't depend upon the temperature, the change of b is adequately described by the well-known Phelps equation:

$$\frac{b_t}{b_0} = \theta^{(T_t - T_0)}$$

which is identical to the overwhelming majority of chemical and biological processes.

Numerical value of the constant θ for two investigated types of sludges, i.e. for the activated sludge of municipal waste waters and activated sludge grown on synthetic substrate, was identical and equal to 1.084. A very close value of θ obtained by P. Benedek (Hungary) and equal to 1.080 gives us the reason for considering the value θ being practically identical for all kinds of activated sludge.

In order to check the effect of sludge age upon values A and b experiments were carried out with six activated sludges of different age (from 3 to 17 days) grown on synthetic substrates and real waste waters. The values A and b were determined to have been reduced as the age of the sludge increased, this relationship is adequately described by fractional-linear functions of the type:

$$b = \frac{C_1}{1 + C_2 T}$$

$$b = \frac{C_3}{1 + C_4 A T}$$

where $C_1 \ldots C_4$ are empiric coefficients,

T is sludge age, days.

Graphic forms of Equations 10-11, where the value S is expressed in units of COD and MLVSS are shown in Fig. 3.

As mentioned above, the uniform stability criterion is not available in the world practice. That is why for approximate evaluation of stability we suggest that the off-gas quantity evolved from aerobically stabilized sludge during its anaerobic final digestion should be compared with the quantity of off-gas evolved from the municipal waste water sludge after digestion in digestion tanks.

Digestion tanks of one of the Moscow aeration stations were chosen standards. Tests for final digestion of digested sludge samples taken from this station showed that the specific gas evolution averages 125 mg/l of MLVSS fed for final digestion. Thus we assumed that the sludge can be considered stabilized if its specific gas evolution value did not exceed 125 mg/l of MLVSS fed for final digestion.

As experiments showed, the quantity of gas released per unit of MLVSS degraded in the process of final digestion averaged 850 mg/l MLVSS and depended neither upon the type of sludge nor upon the degree of stabilization.

Having determined the gas release values of stabilized and incoming sludges of 125 and 850 mg/l respectively, one may write down the following

$$850\,Sa_0 \le 125(Sa_0 + Si)$$

then

$$\beta = \frac{Sa_0}{Si} \le 0{,}173$$

where β is the stability criterion showing the maximum permissible relation of the active organic matter to the inert one in the stabilized sludge.

Now we can derive the calculation formula for determination of basic parameters for the aerobic stabilization process, that is for t and g.

Having put formulas 9, 10, 11 and 13 into Equation 7 we obtain:

$$t_{pf} = \frac{[\text{illegible}]}{[\text{illegible}]}(1+0.06[\text{illegible}])$$

where T_1 – design temperature in the aeration tank, °C;
T_2 is design temperature in the stabilization tank, °C.

Graphs for equation 14 at design temperature in the stabilization tank $T_2 = 20°C$ is presented in Fig. 3.

In order to apply the formulas obtained for the ideal plug-flow reactor to the recommended multi-cell reactor, coefficient α was introduced. Then we obtain:

$$t_{mc} = \alpha t_{pf}$$

Joint solution of equations 7, 9, 10 and 11 gives us the following expression for the calculation of coefficient α:

$$\alpha = \frac{n([\text{illegible}])}{\ln [\text{illegible}]}$$

The value α depends upon the number of cells n and upon sludge age T. Sectioning of a single-cell reactor (a mixing reactor) leads to the sharp reduction of α and therefore t_{mc}, however the efficiency of sectioning reduces as the number of n decreases. More than 8 cells is not considered to be appropriate. At n=8, α is equal to 1.05-1.15.

On the basis of the previously proved equality between the quantity of oxygen consumed and the amount of COD removed one can derive the equation for determination of g:

$$g = [\text{illegible}]\ \text{kg}O_2/\text{kg MLVSS}$$

It is seen from formula 17, that g depends on sludge age only. The graph of Equation 17 is presented in Fig. 4.

Being rather complicated formulas 14-17 are obviously not available for engineering calculations. When the sludge age ranged from 3 to 30 days they can be substituted for more simple and approximate ones:

$$t_{pf} = [\text{illegible}]/1.084^{(20-T_2)}\ \text{day}$$

$$\alpha = 1 + \frac{3.0 + 0.45[\text{illegible}]\ 0.8n}{n[\text{illegible}]}$$

$$g = \frac{0.000 + 0.016T}{1 + 0.14[\text{illegible}]}\ \text{kg}O_2/\text{kg MLVSS}$$

For approximate calculations one can assume that at the most wide-spread sludge age of 3-10 days the stabilization time at calculated temperature in the stabilization tank of 20°C is equal to 8-10 days.

Increase or decrease in temperature by 10°C in its turn decreases or increases stabilization time respectively 2.5 times.

Specific amount of air at the aeration tank depth of 4m and at diffused aeration with the incoming sludge concentration of 30 g/l will be of 460-670 m³ per m³ of the incoming mixed liquor, or at t=8 - 10 days it will be 2.4 - 2.8 m³ per m³ of the stabilization tank volume per hour.

It should be noted, however, that formulae 18 and 20 are valid only for the sludge grown on wastewater containing negligibly small amount of suspended solids as compared to the excess sludge amount. The above stated results were obtained on such waste waters exactly. Qualitative and quantitative composition of suspended solids can effect on stabilization parameters, this effect is impossible to be determined.

The above stated is valid also for the cases of stabilization of raw sludge and secondary sludge mixture. Therefore when waste water fed to aeration tanks contains great amount of organic suspended solids or in case of stabilization of primary and secondary sludge mixture, it is preferably to determine stabilization parameters experimentally. On the basis of investigations carried out we suggest the following rather simple procedure of experiment which does not take more than a fortnight.

1. The process of stabilization of activated sludge or primary and secondary sludge mixture is being carried on under the constant conditions which are modelling the process in the plug-flow reactor. MLVSS and COD of mixed liquor are determined in the course of the experiment.

2. Constants A and b, as well as B and corresponding a_1 are calculated from the obtained curves of the biological mass concentration decrease (in units of MLVSS and COD).

3. The value t_{st} is being determined by formula 7.

4. The value η being equal to the value of mixed liquor COD reduction is determined either graphically or analytically.

Application 1

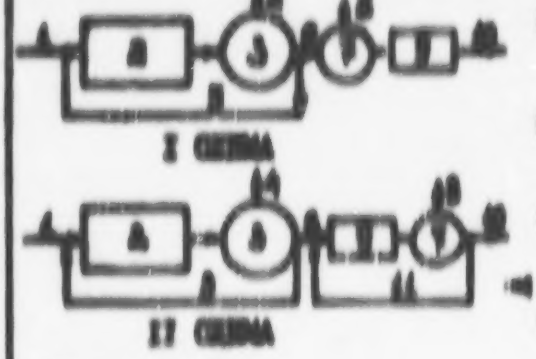
Fig. 1 Technological schemes of aerobic stabilization process.

1. feed waste water
2. aeration unit
3. secondary settling tank
4. effluent
5. returned sludge
6. excess sludge
7. sludge thickener
8. supernatant
9. stabilization tank
10. stabilized sludge
11. stabilized sludge recirculation

Fig. 2 Relationship between A and b constants and sludge age.

Fig. 3 Relationship between t_{st} and η and T_1 at T_2 = 20°C.

Fig. 4 Relationship between g and sludge age.



1 - сточная вода
2 - аэротенк
3 - вторичный отстойник
4 - очищенный сток
5 - возвратный активный ил
6 - избыточный ил
7 - илоуплотнитель
8 - иловая вода
9 - стабилизатор
10 - стабилизированный ил
11 - рециркуляция стабилизированного ила

Рис. 1. Технологическая схема процесса аэробной стабилизации.

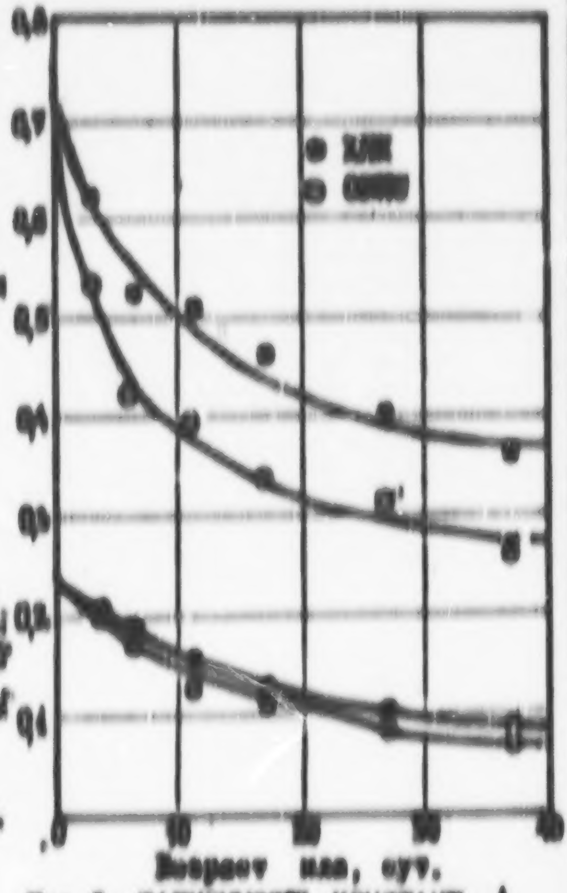


Рис. 2. Зависимость констант A и n от возраста ила.

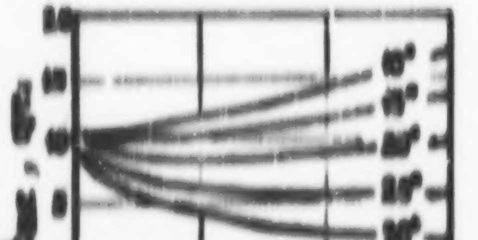


Рис. 3. Зависимость Iоп от возраста ила при $T_1=20°C$ и различных значениях T_2.

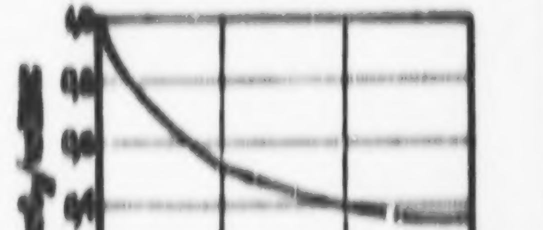


Рис. 4. Зависимость величины β от возраста ила.

THICKENING OF SLUDGES

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from Proceedings of the National Conference on Municipal Sludge Management, Pittsburgh, Pennsylvania, June 11-13, 1974, Information Transfer Incorporated, Washington, D.C., 71-78 (1974)

ABSTRACT

The extent to which sludges are thickened has a significant influence on the overall cost of sludge treatment and disposal. Yet, rational approaches to the design and operation of thickeners to accomplish an optimal degree of thickening have not traditionally been implemented. The purposes of this paper are to review basic thickening concepts and to illustrate that appreciable cost savings may be realized by avoiding the use of conventional, arbitrary, design loadings for thickeners. Instead, thickeners should be designed to achieve a degree of sludge concentration which, in concert with other sludge treatment processes, minimizes overall sludge treatment and disposal costs.

INTRODUCTION

Thickening inevitably is involved in all schemes for treatment and disposal of sludges. Often, separate thickeners are used to reduce the volume of sludge contributed by wastewater treatment processes prior to subsequent sludge treatment and disposal. However, even if a separate thickener is not provided, thickening is still involved in sludge treatment and disposal schemes. This is because facilities which separate solids from the wastewater treatment process and direct them to sludge handling and disposal facilities normally involve use of sedimentation basins. Such basins serve to clarify wastewater prior to discharge and, indeed, frequently bear the name "clarifier." In addition to accomplishing clarification, these sedimentation basins also are expected to concentrate or "thicken" the solids separated from the wastewater. The concepts of thickening discussed in this paper relate as much to the thickening function of sedimentation basins as to thickening occurring in separate sludge thickeners. In either case, clarification also is going on and must be considered in the design.

In spite of the frequent use of separate thickeners in sludge treatment and disposal schemes, as well as the more common occurrence of thickening within sedimentation basins, the design and operation of such facilities has not usually been accomplished on a rational basis. Thickeners ordinarily have been designed using arbitrary design standards with a little consideration being given to the performance which should be anticipated or to the possible benefits of constructing a thickener of different size. Also, in design, the interaction of thickeners with other treatment and disposal processes has not been rationally evaluated. Yet, because the performance of thickeners influences the performance of other processes, some optimal degree of thickening must be appropriate for each particular sludge and sludge treatment and disposal scheme. Similarly, those charged with the operation of thickeners usually have not explored, on a rational basis, the manner in which these facilities should be operated to make optimal use of the installed thickener capacity.

The technology for making rational assessments in the design and operation of thickeners would seem to be available. The purpose of this paper is to review those concepts and to show their utility in design and operation of wastewater treatment facilities. To do this, thickening theory will be briefly reviewed, the interactions of thickening with other sludge treatment and disposal processes will be discussed, and the economic implications of these interactions will be illustrated.

The Rational Analysis of Thickener Performance

Rational bases for design of thickeners and for analyzing the performance of existing thickeners have been presented[1] and reviewed[2,3] elsewhere and the concepts will only be capsulized here. The following discussion is oriented to gravity thickeners, but is applicable to flotation thickeners by substituting the rate for the settling velocity and reversing the direction of the movement of tank content due to sludge removal.

The basic concept in thickener design is to provide sufficient area so that the solids loading per unit area per unit time (the applied flux, ordinarily expressed as lb/sq ft/day) does not exceed the rate at which solids can reach the bottom of the gravity thickener (or top of the flotation thickener). The rate at which solids can reach the bottom of a thickener depends on the rate at which they settle under the influence of gravity and the rate at which they are transported through the thickener due to removal of thickened sludge. That is

$$G_t = c_i v_i + c_i u \qquad (1)$$

where G_t is the possible flux of solids through a layer of concentration c_i, v_i is the gravity settling velocity of the sludge solids at concentration c_i, and u is the bulk downward velocity in the thickener produced by the removal of sludge from the bottom of the tank. Equation 1 is an expression of the possible rate of solids transport per unit area for any concentration in a continuous thickener (one from which thickened sludge is continuously withdrawn). Batch thickeners are a special case in which the $c_i u$ term in Equation 1 is zero.

It should be noted that the $c_i v_i$ term in Equation 1 depends only on the physical properties on the sludge and is not susceptible to control by the designer or operator of the thickener unless physical, biological, or chemical alteration of sludge solids (as by use of a polyelectrolyte) is practiced. In contrast, the magnitude of the $c_i u$ term in the equation depends on the rate at which thickened sludge is removed from the bottom of the tank, and is therefore susceptible to control by the thickener designer and operator.

For optimal performance of a thickener, sludge removal equipment must be designed to uniformly collect thickened sludge from the bottom of the tank so that

$$u = Q_u / A \qquad (2)$$

where Q_u is the volumetric rate of removal of thickened sludge from a continuous thickener of area A. Thus, it is seen that the capacity of a thickener for receiving sludge solids can be increased by increasing the rate of removal of thickened sludge. While this may be a desirable course of action for an overloaded thickener, it conflicts with the basic goal of thickening: the production of a concentrated thickening underflow. This is because

$$Q_u = c_f Q_f / c_u \qquad (3)$$

and it is desired to maximize the underflow concentration, c_u. Equation 3 was obtained from a mass balance on a thickener receiving feed sludge at a volumetric flow rate, Q_f, with a suspended solids concentration, c_f, assuming that the clarified effluent from the thickener was essentially free of suspended solids.

If the relationship between settling velocity, v_i, and concentration, c_i, is known (see Reference 3 for procedures and difficulties in determining the settleability of sludges), and if a value of u is selected, then the value of the batch flux and underflow flux in Equation 1 can be determined for each possible concentration of sludge which might exist in a thickener.

Figure 1 illustrates the variation of these two terms in Equation 1 with suspended solids concentration and shows the resulting total flux, G_t, possible for each concentration of sludge which might exist in a thickener. It is seen that, in the higher range of concentrations which typically exist in thickeners the value of G_t passes through a minimum. It is this limiting capacity for transmitting solids to the bottom of a thickener, G_L, which limits the capacity of thickeners. Thus, one must ascertain that solids are not applied at a rate greater than G_L, or

$$A = c_f Q_f / G_L \qquad (4)$$

It should be noted that, because u, the underflow velocity, is controlled by the designer or operator of a thickener, the value of G_L is controllable. Thus, for a thickener receiving a given solids load ($c_f Q_f$), the value of G_L in Equation 4 can be varied to give any desired thickener area. However, from Equation 1, it can be seen that if a high value of G_L is selected, a high value of u, the underflow velocity, must also be used. From Equations 2 and 3, it is seen that the use of a high underflow velocity would result in the removal of dilute sludge from the thickener. When a new thickener is being designed, area, and thus underflow velocity, are unknown. Thus, the solution outlined above becomes a laborious trial and error situation. This difficulty can be circumvented by use of a graphical solution[4]. This simplified procedure is highly recommended for design and routine analysis of the performance of existing thickeners.

Interaction of Thickening with Other Sludge Treatment and Disposal Processes

To illustrate the influence of gravity thickening of the economics of sludge treatment and disposal, the cost of thickening a typical municipal sludge to various concentrations was compared with the savings resulting from the improved thickening in the cost of various sludge treatment techniques. To illustrate the effect of the size of the waste treatment facility on the economics of thickening, calculations were conducted for cities of 10,000, 100,000, and 1,000,000 people.

TOTAL FLUX = TRANSPORT DUE TO SEDIMENTATION + TRANSPORT DUE TO SLUDGE REMOVAL

$$G_i = c_i V_i + c_i \frac{Q_u}{A}$$

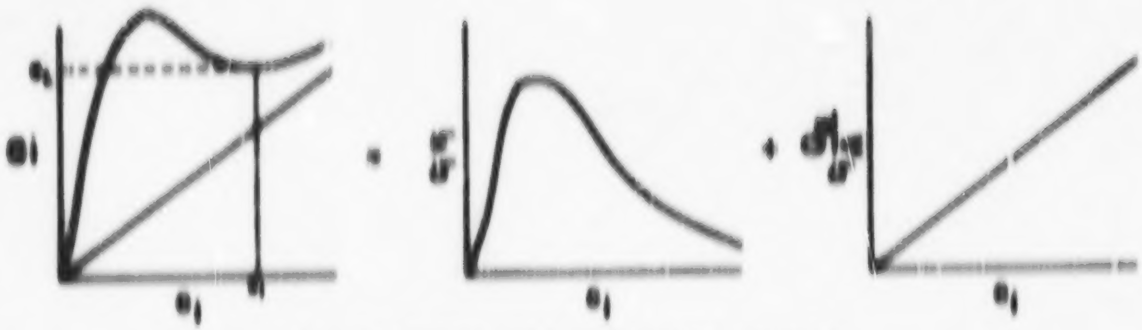

Figure 1 Determination of Allowable Loading on a Thickener

Sludge Quantities

The following equation was developed to estimate the quantities of sludge to be treated by the various sized cities:

Production of Sludge = suspended solids removed in primary clarifier
+ nonbiodegradable volatile solids in raw waste which become incorporated in activated sludge
+ nonvolatile suspended solids carried into activated sludge process
+ synthesis of activated sludge solids
+ any organic precipitates formed during biological treatment
− autooxidation of biological solids
− suspended solids lost in effluent

This equation may be written as

$$S = [P_{ss} C_{ss} + fh(1 - P_{ss}) C_{ss} + (1-h)(1-P_{ss}) C_{ss} + a(1 - P_{BOD}) C_{BOD} m_{BOD} + C_p - b(1 - P_{BOD}) C_{BOD} m_{BOD} - C_{se}] Q \quad (5)$$

The meaning of symbols in Equation 5 is indicated below along with dimensions

a = amount of biological synthesis per unit of BOD removed, lb suspended solids/lb BOD (0.5).

b = fraction of mixed liquor volatile suspended solids which are autooxidized daily, dimensionless (0.1).

S_{BOD} = concentration of BOD in raw waste, M/L³, (175 mg/l)
C_p = concentration of inorganic precipitate formed during biological treatment, M/L³, (0 mg/l)
X_e = concentration of suspended solids in effluent from treatment plant, M/L³, (15 mg/l)
X_o = concentration of suspended solids in raw waste, M/L³, (200 mg/l)
f = fraction of volatile suspended solids entering aeration tank which are not biologically oxidized, dimensionless, (0.35)
h = fraction of suspended solids entering aeration tank which are volatile, dimensionless, (0.75)
L = organic loading intensity to activated sludge process, lb BOD removed/lb volatile suspended solids in aeration tank, (0.4)
E_{BOD} = fraction of BOD entering the secondary process which is removed (based on filtered effluent sample), dimensionless, (0.90)
P_{BOD} = fraction of BOD removed in primary settling tank, dimensionless, (0.33)
PSS = fraction of suspended solids removed in primary settling tank, dimensionless, (0.6)
Q = wastewater flow rate, L³/T, (at 135 gpcd)
S = daily production of waste sludge solids, M/T

Equation 5 is a modification of Schneider's Equation 11.5[5] with the addition of terms to account for primary sludge, any organic solids precipitated in the biological reactor[6], incorporation of non-volatile solids contained in the raw waste into activated sludge, and the loss of solids over the final sedimentation tank weir. Values of the various constants as assumed for purposes of this illustration are indicated in parentheses in the preceding list. All of these values are subject to variation from waste to waste and none are necessarily applicable to any particular plant. In the absence of information on the amount of inorganic precipitants formed during biological treatment, this contribution toward sludge production was ignored. A waste flow rate of 135 gpcd, a per capita suspended solids loading of 0.25 lb/day, and a per capita BOD contribution of 0.2 lb/day were assumed based on data presented by Loehr[7]. No allowance was made for the probable variation in quality and quantity of waste as a function of the size of the municipality.

Based on the assumed values, sludge production per million gallons of wastewater flow would be [illegible] lb/day of which [illegible] lb/day would be primary sludge, and [illegible] lb/day would be waste secondary solids. The magnitude of this sludge production is perhaps on the low side of reported experience.

Cost of Gravity Thickening of Sludge

To obtain an indication of current probable costs of thickening and to achieve a basis for illustrating the integration of thickeners with other processes of sludge handling and disposal, estimates were developed for the cost of thickening sludge to various degrees in municipalities of various sizes. This was done by assuming sludge settling properties (settling velocity as a function of concentration), determining the allowable loading on a thickener to concentrate the sludge to varying degrees, sizing the thickener, and estimating the cost of construction and operation of the thickener of the necessary size.

REQUIRED THICKENER SIZE. As described in an earlier section, the required size of a thickener is a function of the extent to which it is desired to concentrate sludge and of the settling characteristics of the sludge being thickened. In this illustration, the settling properties of a combined primary-secondary sludge were assumed and expressed in the form of an equation used by Dick and Young[8]

$$v_i = a c_i^{-n} \qquad (6)$$

where v_i is the settling velocity of sludge at concentration c_i and a and n are constants characterizing the properties of the particular sludge being considered. For purposes of this illustration, a was taken as [illegible] ft/min, and n as [illegible], when v_i is expressed in ft/min and c_i in percent.

The allowable solids loading (the limiting flux) for achieving various degrees of concentration of the sludge were calculated and are shown in Figure 3 along with the resulting required total thickener area for a city of 100,000. Because no differences in sludge production between cities of various sizes are considered, the required thickener areas for achieving various degrees of sludge concentration for cities of 1,000,000 and 10,000 are an an order of magnitude more or less than the values shown in Figure 3.

THICKENER COSTS. In addition to requiring an understanding of factors affecting process performance, optimal integration of sludge treatment processes requires information on the cost of treatment by various techniques as a function of the level of process performance. Unfortunately, optimal selection, design, and operation of sludge treatment processes is hampered by a dearth of such cost information. In the case of gravity thickening, such data are in particularly short supply. This is, perhaps, because thickening normally is the cheapest step in sludge treatment and disposal and, thus, thickening costs often tend to be lumped into the cost

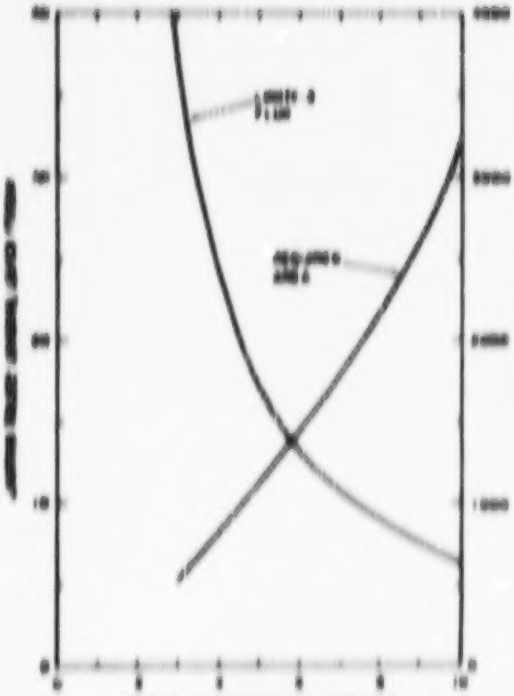

Figure 3. Required Size of Thickener for Concentrating Hypothetical Sludge to Varying Degrees in City of 100,000 People

of other sludge processing techniques. Additionally, sludges vary widely in their thickening characteristics, and unit costs for thickening would be expected to vary accordingly. As with all current cost estimations, inflation also imposes complications. In Burd's review[1] of the state of the art in sludge handling and disposal, it was generalized that separate sludge thickening costs from two to five dollars per ton of dry solids. Smith[13] presented equations for the cost of construction of gravity thickeners as a function of area. In neither case was the thickening cost related to the degree of sludge concentration achieved. That was accomplished here by estimating the cost of the thickeners used (Figure 3) to give various degrees of sludge concentration.

Capital costs for thickeners of various sizes were obtained by adjusting cost data presented by Smith[13] to April, 1974 on the basis of the Engineering News Record Construction Cost Index (the April, 1974 value being 1940) and then increasing the cost by 25 percent to account for contractor's profit, contingencies, and engineering. The resulting capital cost equation was

$$C_0 = [54.3 + 26.3e^{-A/8000}]A \qquad (7)$$

Extensive data on the operation and maintenance of gravity thickeners as a function of their size were not available. In the absence of such information, costs reported by Smith[13] on operation and maintenance costs for primary clarifiers as a function of their area were used. It was assumed that the equipment and operational requirements were similar to separate thickeners. Arbitrarily, Smith's operational and maintenance costs were adjusted by use of the Engineering News Record Construction Cost Index to make some allowance for changes in costs of labor and materials since his work was published. The resulting equation for an annual operating and maintenance costs as a function of thickener area was

$$OM_s = 2.39A + 180A^{0.5} \qquad (8)$$

To obtain an overall cost of thickening to various degrees, annual costs (operation and maintenance plus amortization of capital costs) were calculated. Then, as shown on Figure 4, costs of thickening to various degrees for various sizes of municipalities could be expressed on the basis of total cost per unit of sludge production. For this purpose, the approximate current interest rate on Grade A municipal bonds (6½ percent) was used with a 30 yr amortization period.

Thickening and Dewatering of Raw Sludge

The yield of sludge dewatering devices is increased when water is removed from sludge (as by gravity thickening) prior to being fed to the dewatering device. This is because less water must then be passed through the somewhat impermeable sludge cake in the course of dewatering than would be necessary if the excess water was not removed previously by thickening. Additionally, the degree to which sludge can be mechanically dewatered increases when concentrated sludge is fed to the dewatering equipment[8].

To illustrate the optimal integration of thickening and dewatering processes, the cost of sludge dewatering by vacuum filtration was considered. Then, the total cost of the combination of the thickening and dewatering processes could be evaluated to determine the proper design for each of the two processes.

The effect of feed sludge concentration of filter yield was taken from data presented by Schepman and Cornell[13] which indicated that

$$Y' = 0.88C_u - 1.0 \qquad (9)$$

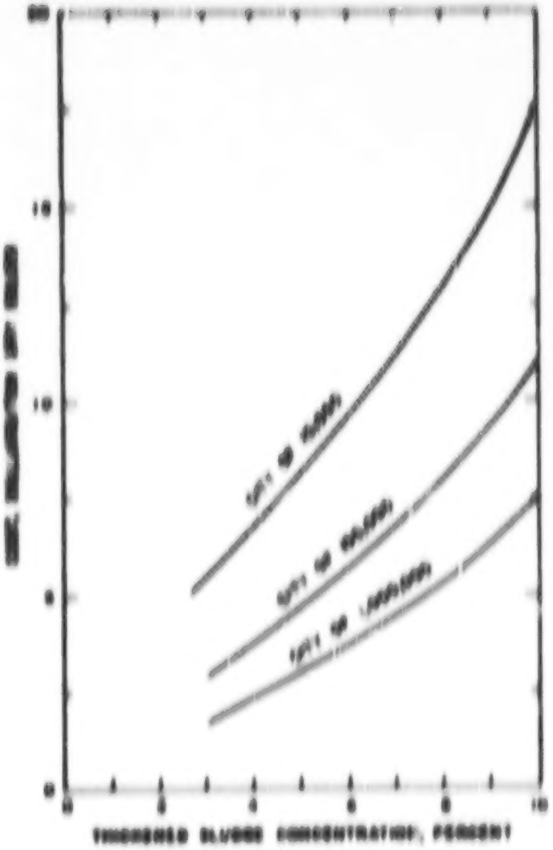

Figure 3 Costs of Thickening Hypothetical Sludge to Varying Degrees

where Y is the filter yield in lb dry solids/hr/sq ft, and C_u is the concentration of sludge in the thickener underflow. Extrapolation of the Schepman and Cornell data was necessary to include the range of interests here, but the extrapolated data agreed closely with information on relationship between feed solids concentration and filter yield presented in Quirk[10].

Capital costs for vacuum filters were taken from information presented by Smith[11]. As with the capital costs for thickeners, Smith's estimates were adjusted to the April, 1974 Engineering News Record Construction Cost Index of 1940 and then 25 percent was added for contractors profit, contingencies, and engineering. Capital costs were amortized at 6.5 percent for 20 yr. Costs for labor, power, and maintenance were taken from estimates prepared by Quirk[10] and, arbitrarily, were adjusted to current costs by use of the Engineering News Record Construction Cost Index. Chemical costs for sludge conditioning were taken as $12/ton of dry solids and were not considered to vary with the size of the city or the extent to which the sludge was thickened.

Resulting total costs for thickening and dewatering are shown in Figure 4. The contribution of thickening and vacuum filtration (including conditioning) to the total cost is illustrated for the city of 1,000,000. Total costs curves are shown for all three cities. The relative contribution for thickening and dewatering to the total cost for cities of 10,000 and 100,000 people can be obtained by comparing Figures 3 and 4.

It is seen from Figure 4 that the optimal degree to which the sludge considered here should be thickened for the city of 10,000 people is about 8 percent. For the two larger cities, a total cost became relatively insensitive to the degree of thickening at a concentration of around 8 percent, but a true optimum was not reached within the range of concentrations considered. While the thickening costs involved in reaching these high concentrations are in excess of the costs normally considered for thickening, results would suggest that, with this sludge and these estimates of capital and operating costs, more money should be spent for thickening than is normal practice. However, because sludge properties vary from plant to plant, the more important point is that great savings in the combined cost of thickening and dewatering is possible by use of a rational approach to design of sludge treatment systems.

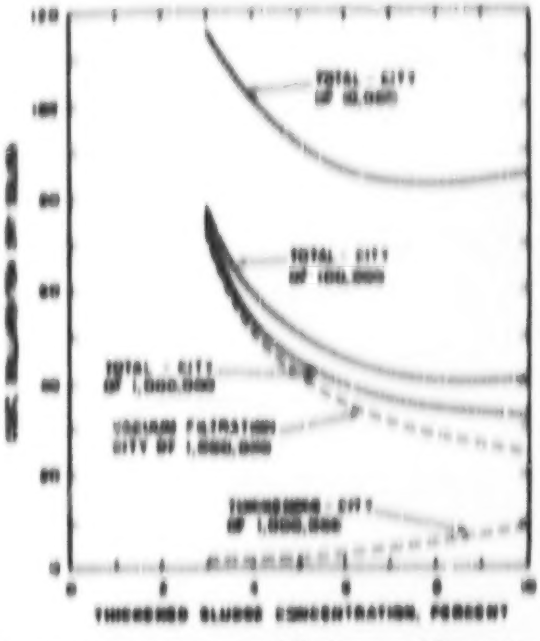

Figure 4 Optimal Integration of Thickening and Dewatering

Overall Costs of Thickening and Transporting Sludge by Truck

To illustrate the effect of thickening on another phase of sludge handling, overall costs of thickening and subsequent trucking were evaluated for thickeners designed to achieve varying degrees of sludge concentration. For this purpose, trucking costs were taken from estimates prepared by Riddell and Cormack[11] for trucking sludge a distance of 25 miles. Riddell and Cormack's data (which were developed for sludge at 3.5 percent concentration) were adjusted to evaluate the cost of transporting different volumes of sludge containing the same total amount of dry solids. Figures then were adjusted for inflated labor and materials costs by use of the Engineering News Record Construction Cost Index.

Total overall costs for thickening and transporting sludge 25 miles by truck for various sized cities are illustrated in Figure 5. Again, the breakdown of costs is shown only for the city of 1,000,000 people, but the relative contributions of trucking and thickening for the cities of 100,000 and 10,000 people can be obtained by comparing Figures 3 and 5. As before, a true optimum was not achieved within the range of sludge concentrations considered. That is, even though sludge thickening became far more expensive than usual, the incremental cost was justified by the reduction in the cost of transporting the sludge.

SUMMARY AND CONCLUSIONS

Thickening is involved in all schemes of sludge treatment and disposal. If a separate gravity or flotation thickener is not used, then thickening still is involved because it occurs in the sedimentation tanks which produce the sludge. Thickening has a great influence on the cost of sludge treatment and disposal because the cost effectiveness of sludge treatment and disposal techniques depends on the concentration of solids in the sludge.

Traditionally, thickeners have been sized in an arbitrary fashion without regard to the thickening properties of the sludge being treated or to the degree of thickening desired. Yet the size of a thickener does affect the amount of thickening achieved and this effect can be estimated if the settling characteristics of the sludge are known. This allows thickeners to be designed and operated to achieve any desired degree of sludge concentration. The degree to which sludge should be concentrated in a thickener depends on factors such as the nature of the sludge, the size of the community, and the types of other sludge treatment and disposal processes involved in the system.

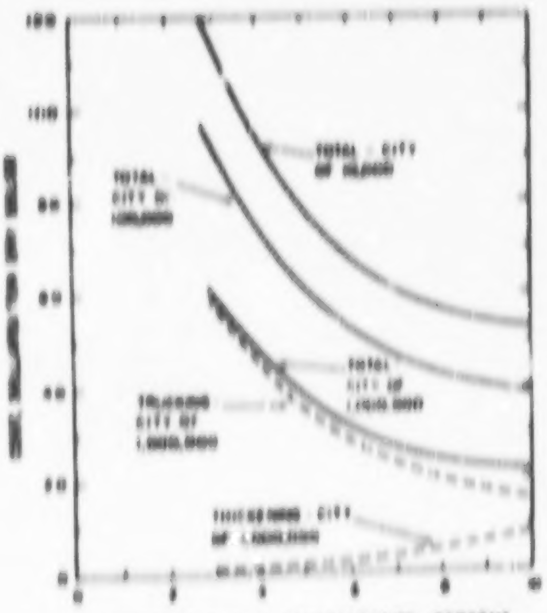

Figure 5. Optimal Integration of Thickening and Trucking

The effect of designing thickeners to accomplish varying degrees of solids concentration on sludge treatment and disposal costs are illustrated herein. Integration of the design of thickeners with the design of other processes offers significant potential for reducing costs. While this approach to the design of sludge treatment and disposal facilities requires appreciably more information about sludge treatability than normally is available, the results suggest that the potential cost savings warrant the cost of conducting the special studies required.

ACKNOWLEDGMENTS

This work was supported in part by funds provided by the United States Department of the Interior as authorized under the Water Resources Research Act of 1964, Public Law 88-379.

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DISSOLVED AIR FLOTATION THICKENING AS PRACTICED IN THE U.S.

By

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DISSOLVED AIR FLOTATION THICKENING[1] AS PRACTICED IN THE U.S.

By
William H. Konrad[2]

One of the most essential requirements in the disposal of solids from wastewater treatment plants is that of thickening or reducing the water content of sludge in order to insure the effectiveness of subsequent disposal processes. The utilization of thickening by gravity sedimentation is well known, quite well documented, and has been employed successfully in this field. However, since the early 1950's, and since the increased usage of the activated sludge process, where larger volumes of sludges are generated, the application of dissolved air flotation for thickening has increased in the United States. Today, a large majority of the designers requiring thickening of biological sludges utilize dissolved air flotation as an integral part of their sludge handling process, since dissolved air flotation has not only demonstrated its ability to reduce the hydraulic loading on subsequent units, it has also allowed an increase in applied solids loadings to these processes.

Figure No. 1 illustrates where flotation thickening is used in the various sludge handling schemes employed by municipal wastewater treatment plants.

Generally, dissolved air flotation is not applied on primary sludge alone; however, there have been instances where designs are based on sludge mixtures where occasionally primary sludge alone has been thickened. The primary reason for not using dissolved air flotation on primary solids is that it is generally possible to obtain the necessary concentration in the sedimentation basin. Also, when thickening of primary sludge is required, the use of a gravity thickening device will be the most economical to achieve the desired results.

This figure essentially shows the application of dissolved air flotation thickening on secondary sludges, either humus sludge or activated sludge, and with or without the addition of primary sludge.

It should be noted that dissolved air flotation has been applied on aerobically digested sludge, but it has been used very selectively. In a number of pilot plant operations, results obtained have been poor and erratic. One successful installation utilizing this process has demonstrated that it can achieve a 4% sludge concentration at a solids loading of 20#/sq. ft-day (97.65 kg/sq. meter-day) without the use of chemical aids. This is one area that requires further research before general usage can be claimed.

Concentrating humus sludge has not found general application since trickling filters are generally used in small municipalities. It has been shown to be uneconomical to use flotation thickening where a small amount of sludge is generated. In larger plants employing trickling filters, we find that the humus sludge is handled with the primary sludge and should an activated sludge plant also be located on the same site, the humus sludge will be handled with the activated sludge. For purposes of design, we have assumed that humus sludge does behave like activated sludge. The applied load generally is not very great and permits a conservative approach.

One increasing area in the application of dissolved air flotation is that preceding anaerobic digestion, which, incidentally, is also increasing in use in the United States. In addition to better utilization of digestion volume through water reduction, the dissolved air flotation thickener has demonstrated effective separation of grit from the sludge flow. One installation which we are familiar with, which concentrates mixtures of primary and activated sludge, has removed over a cubic yard (3/4 cu. meter) of grit from 12,000 lbs. (5450 kg.) of primary sludge each day. Being able to do better degritting prior to digestion decreases maintenance costs and provides additional volume for digestion.

This figure also shows thickening before vacuum filtration or centrifugation. One area of caution is where dissolved air flotation is utilized with chemicals. We have experienced cases where the chemical used in dissolved air flotation process acted antagonistically with the vacuum filter performance.

The design criteria for dissolved air flotation thickening is shown in Figure 2. Design surface loading rates as well as the expected thickened concentration of the sludge are illustrated. (Generally a 4% concentration is an optimum desirable sludge concentration.) This data reflects the situation where chemicals are not used to aid the thickening process. When chemicals are used, they are generally applied when activated sludge alone is thickened. In these cases the surface loading rates can be increased by three to six times that shown in Figure 2, with essentially the same thickened sludge concentration

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[1] Paper presented at United States-Soviet Seminar on "Handling, Treatment, and Disposal of Sludges," Moscow, Russia, May [illegible]

[2] Director Market Development, Envirex Inc., A Rexnord Company, Waukesha, Wisconsin, U.S.A.

[illegible]. Also when chemicals are used, approximately three to ten lbs. (1.36 to 4.5 kg.) of polyelectrolytes are required per ton (907 kg.) of sludge thickened. There have been cases where the sludge was very difficult to concentrate and requirements as high as 30 lbs./ton (14 kg./907 kg.) of polyelectrolytes have been reported.

The subnatant, which is relatively clear underflow, will contain about 1% of the solids that were fed to the unit when no chemicals are used. When a polyelectrolyte is used, the subnatant will be clearer and underflow concentrations of less than 1% can be expected. The subnatant in either case is usually returned to the aeration tank.

When selecting the size of the dissolved air flotation thickener and whether to use or not use chemicals, the designer has several options. The use of chemicals allows for the size of the flotation unit to be smaller, but the operating and maintenance costs will be greater. A number of designers have used a conservative approach to loading, which increases the size of basins but provides a lower operating cost. Others use the conservative approach and make provisions for the later addition of chemical feed equipment as anticipated solids loads increase, while others use the conservative approach but install the chemical feed equipment initially. In these cases, the chemicals may be added initially in very small amounts to improve the subnatant. Where mixtures of primary and activated sludge are thickened, the loadings are generally those shown in Figure 2, and the chemical usage relegated to cleaning up the subnatant and not to increase the applied loadings.

To assist in finalizing a design, and when sludge is available, it is common practice to use a pilot dissolved air flotation unit to obtain accurate design data. Figure No. 3 is a picture of such a unit. If a unit such as this cannot be used, a bench scale test procedure has been developed for predicting the loading rates and the resultant thickened sludge concentration. The apparatus used for this test is shown in Figure No. 4. It is beyond the scope of this text to describe the test details and method of correlation. However, over the last 15 years, a correlation between the sludge concentration developed in the bench test to that of a full scale unit has been established with a high degree of confidence.

DESIGN PARAMETERS OF THE UNIT PROCESS

In the unit process for dissolved air flotation there are several parameters of design which must be considered. Some of these parameters are spacing and speed of flights which remove the surface thickened sludge, frequency of removal, tank configuration, source of pressurized flow and the air to solids ratio (A/S ratio).

Experience over a number of years has dictated that the spacing of flights and speed of skimmer be such that intermittent operation be employed to obtain the optimum in concentration of sludge removal. We have found optimum spacing to be approximately three feet (1 meter), a variable speed of 2 to 8 feet/min. (0.61 to 2.44 meters/min.), and intermittent operation with the timing dependent on tank length, solids loading and desired concentration. Generally this will be between 10 and 50 percent of the time. We also recommend scraping away from the influent end of the tank. Side-by-side tests of duplicate units with only the direction of skimming changed yielded superior results with the skimming in the direction of flow. The reason is that removal is at a point of minimum eddies and maximum sludge blanket thickness.

The tank configuration found to be most successful in obtaining optimum concentration is rectangular. Length to width ratios of three to five to one are generally recommended to allow optimum concentration in the sludge blanket and to balance removal capacity. Tank depths include a sludge concentration zone, a flow-through zone and a depth below this zone to accommodate bottom sludge or grit removal equipment. Some designers have attempted to use hydraulic overflow rates in the design of thickeners, but overflow rates are meaningless since the overriding criterion in establishing the area of the thickener is the applied mass loading.

The source of pressurized flow is also a consideration of the designer. There are three options available. One is the effluent from the thickener itself, the second is the utilization of plant effluent, and the third is the utilization of screened primary tank effluent.

Utilizing subnatant from the thickener tank offers the disadvantage of requiring a back-up source of flow to restart the unit should there be a failure in the air system. The utilization of plant effluent offers a relatively clean source of pressurized flow, but consideration must be given to the added hydraulic flow recycled to the treatment plant. This can be a significant amount to add to a plant facility. The third system has demonstrated reasonable success in the United States, and in this case the pressurized flow is screened primary effluent and essentially is borrowed for the dissolved air flotation system before being returned to the aeration tank. Because the pressurized flow is returned to the aeration tank, it does not impose a hydraulic load on the treatment system.

Of all of the variables mentioned, the one that is of most significant value is the air to solids (A/S) ratio. This ratio is the amount of air applied to a given amount of sludge. The ratio is unitless, kilograms of effective air blended with each kilogram of sludge to be thickened. Since dissolved air flotation has become a major process in the handling of municipal sludges, there has been much controversy as to the optimum A/S ratio which should be used as well as how this solids ratio should be obtained.

The literature has indicated that the pressurizing process should be between 40 and 80 psig (2.8 and 5.6 kg./sq.cm), and the A/S ratio should have a range of 0.01 to 0.06.

Figure No. 5 shows what a dissolved air flotation thickener physically looks like. In this process an external or recycled flow is put under pressure and fed to the unit and mixed with the raw sludge whereby the pressure is released to atmosphere and small microscopic bubbles come out of solution and float the sludge to the surface.

For a given volume of flow to be pressurized, the higher the operating pressure, the more air that can be put into solution. This is one way to increase the amount of air being put into contact with the sludge; thus, the higher the pressure, the higher the A/S ratio. Another way to increase the A/S ratio is to maintain the same pressure but to increase the volume of pressurizing flow for the same amount of sludge being blended.

W. J. Katz and A. M. Geinopolos in the mid 1950's indicated that an optimum operating pressure for a dissolved air flotation unit would be about 40 psig (2.8 kg./sq.cm). Even though you may place more air into solution at a higher operating pressure, the higher pressures release air bubbles that are of an ineffective size (the effective bubble size is under 100 microns). Larger size bubbles pass through the sludge rather than lifting and compact the sludge. R. F. Wood and R. I. Dick in work done in 1974 have reconfirmed the benefits of operating at 40 psig (2.8 kg./sq.cm) rather than 70 or 80 psig (4.9 or 5.6 kg./sq.cm).

To operate at a lower pressure has a real economical impact also, because there is a significant cost difference between air saturating a given flow volume at 40 rather than 80 psig. The requirement for higher feed pumps, larger air compressors, and higher pressure coded pressure tanks contribute significantly to the initial cost of the process and the high horsepower pumps and air compressors increase operating costs.

Figure No. 6 shows some of the results which R. F. Wood and R. I. Dick have produced with regard to increasing the A/S ratio by increasing the pressure. These results which are depicted in Figure No. 6 prove to be a real contribution to the art. These results would not only indicate that attempting to operate at a higher A/S ratio by increasing the pressure is of no benefit, but, in fact, it is detrimental to the thickening process. Again, the reason for this detrimental effect of higher pressures on thickening is that the size of the bubble formed is such that it passes through the sludge rather than lift and compact it.

FIELD PERFORMANCE DATA

Another way to increase the A/S ratio is to operate at the optimum pressure and increase the volume of flow to be pressurized. In the summer of 1973, we had the opportunity of evaluating high rate loadings and various air to solids ratios on a full scale dissolved air flotation thickener. R. F. Wood and R. I. Dick confirmed in the laboratory that increasing A/S ratio by increasing the operating pressure proved to be detrimental to the process. We attempted to confirm this work on a full scale unit having an effective surface area of 150 sq. ft. (14 sq. meters). We not only wanted to again confirm that operating at 40 psi (2.8 kg./sq.cm) was optimum, but we also wanted to determine what the optimum A/S ratio is by changing the pressurized flow volume. Approximately 14 days were spent at the site doing a full scale analysis. The objectives of the test work were as follows:

1. With all other parameters being equal, to determine the efficiency of the unit at 40 psig and 60 psig (2.8 and 4.2 kg/sq.cm) operating pressure.
2. At whichever pressure the unit performed better, to determine the amount or volume of pressurizing flow which may be required to obtain optimum performance (variation of A/S ratio by flow volume). Optimum performance was measured by the maximum thickened sludge concentration which resulted from a given solids loading. The solids loading of the thickener were from 48 to 54 lbs./sq.ft./day (234 to 263 kg./sq. meter/day) with the use of chemicals. Chemical dosages were kept constant for all tests. The duration of the test ranged from 6 to 12 hours. This duration is important because it indicates stability in the operation of the unit. It is very possible to operate at substantially higher loadings but for short periods of time only. However, one cannot operate this process continuously at a sustained higher level for any length of time because the entire process begins to deteriorate very rapidly. What is implied here is, when a unit begins to fail, it does not fail instantly, but it fails by gradual deterioration of the subnatant.

These two test objectives show an attempt to determine what happens when the A/S ratio is changed by changing the pressure and then by keeping the same pressure and changing A/S ratio by changing the volume of recycle flow which contains the dissolved air.

Conclusions on Field Tests (determination optimum A/S)

1. Increase in the operating pressure from 40 to 60 psig indicated deterioration of the performance of the process. With other parameters held equal, the unit produced a cake concentration of 3.4% while operated at 60 psig (4.2 kg./sq. cm.) (A/S equal to 0.020), while at 40 psig (2.8 kg./sq. cm.) (A/S is equal to 0.016), the cake concentration was 4.1%. What is interesting to note here is that the effluent suspended solids concentration in the underflow was 14 mg/l while operating at 40 psig and 300 mg/l while operating at 60 psig. This data reaffirms the conclusion outlined by R. F. Wood and R. J. Dick.

   From these observations, it has been concluded that a change in air to solids ratio by increasing the pressure provided to be detrimental to the operation; and that 40 psig (2.8 kg./sq. cm.) is the optimum operating pressure.

2. Since 40 psig (2.8 kg./sq.cm.) proved again to be the optimum operating pressure, the operating air to solids ratio was then changed by the changing of the recycle flow volume. Figure No. 7 shows the results. These results show conclusively that there is optimum air to solids ratio when operating at 40 psig (2.8 kg./sq.cm.) and that higher air to solids ratios again prove to be detrimental. As can be seen from Figure No. 7, the design point with respect to air to solids ratio proves to be about 0.014 at 40 psig (2.8 kg./sq.cm.).

This A/S ratio can be converted directly to a practical design approach by using 100% recycle or pressurized flow for every 1/2 percent of influent sludge concentration while operating at 40 psig (2.8 kg./sq.cm.). This value results in an A/S ratio of about 0.015.

As the various parameters discussed are more fully understood and a better understanding of the importance of operating with the optimum A/S at 40 psig (2.8 kg./sq.cm.) (optimum operating pressure), the application of dissolved air flotation for sludge thickening will increase. This process has demonstrated that it has the capability of performing an economical and necessary function in the entire sludge handling scheme.

Figure No. 1

COMMON SLUDGE HANDLING SCHEMES

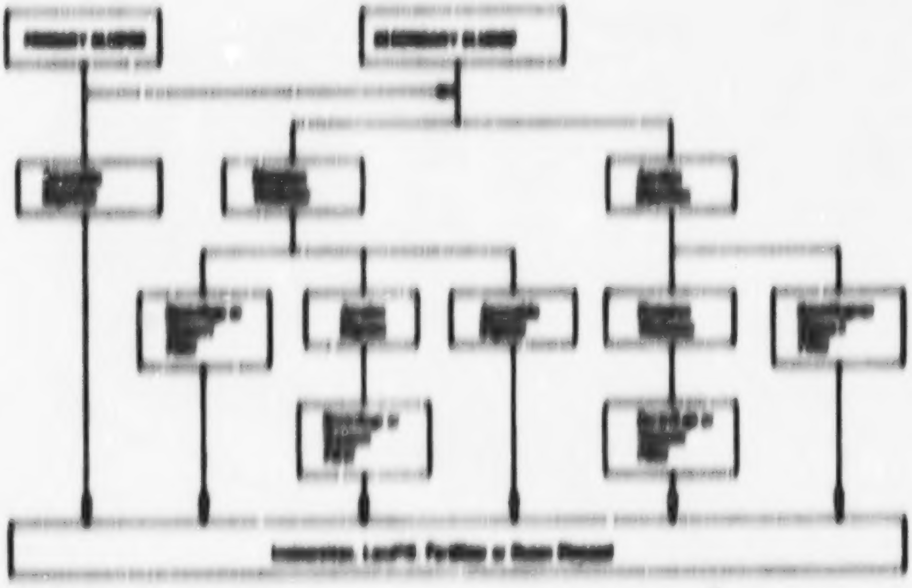


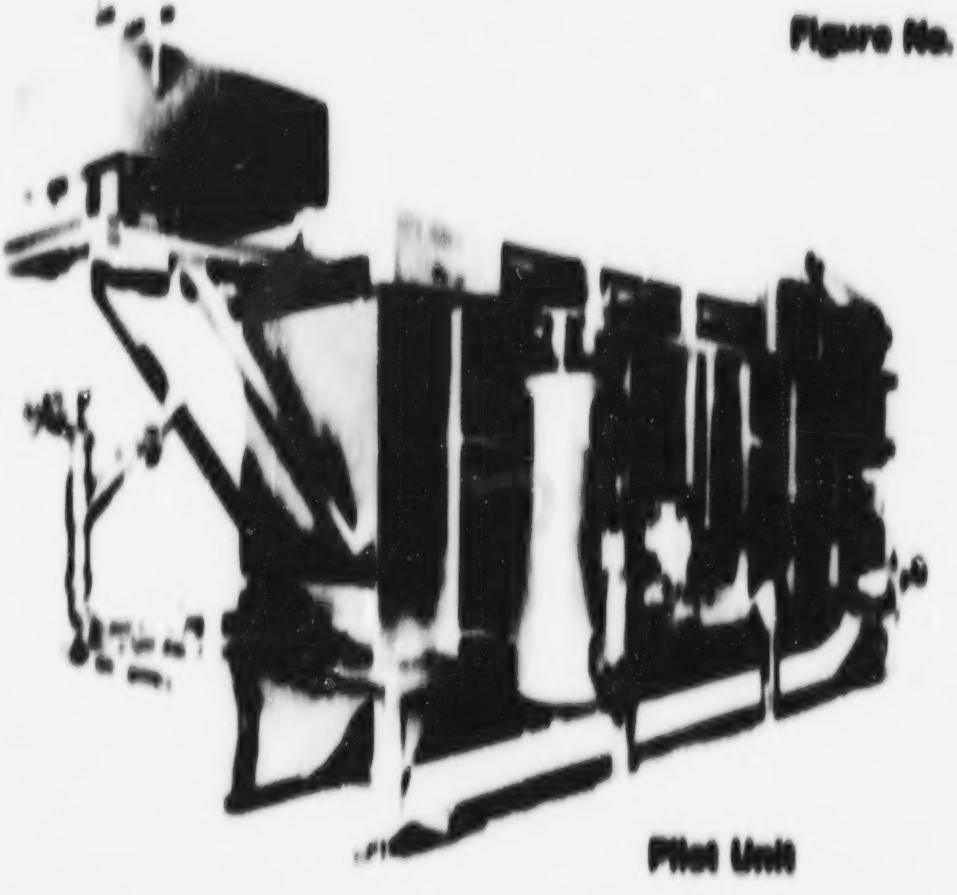
Figure No. 2

DESIGN LOADINGS FOR FLOTATION THICKENING

Type of Sludge	Surface Loading lbs/day/ft²	Thickened Concentration %
Primary	20 : 30	7 : 10
Activated	3 : 15	3 : 6
Primary & Activated	20 : 30	5 : 10
Primary & Trickling Filter	20 : 30	5 : 10

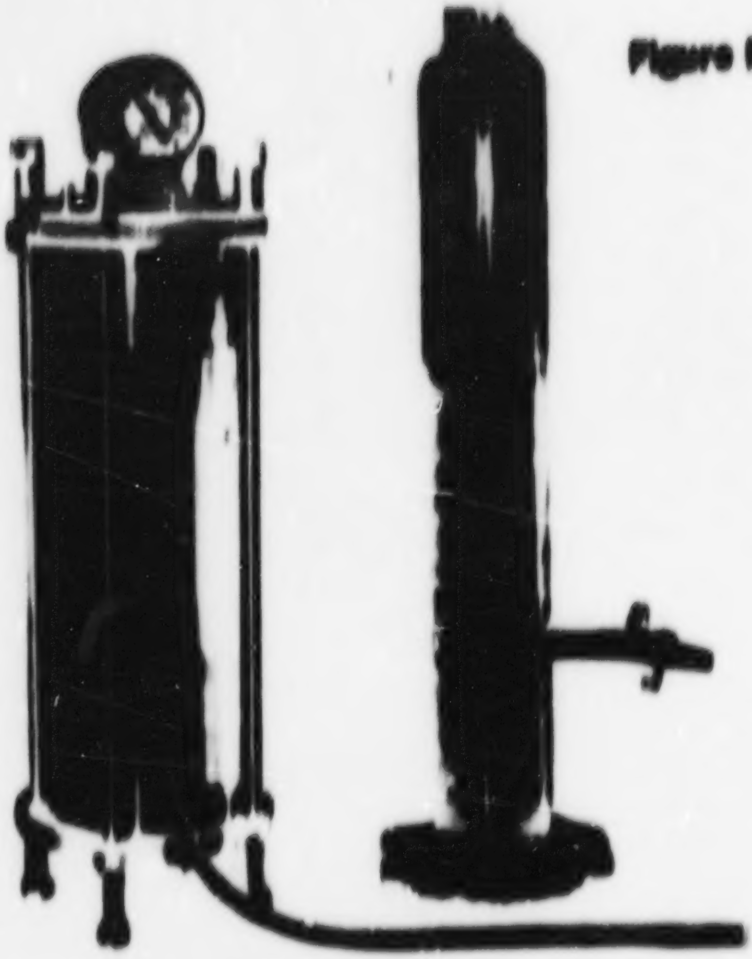
This data is for thickening without the use of chemicals.

Figure No. 3



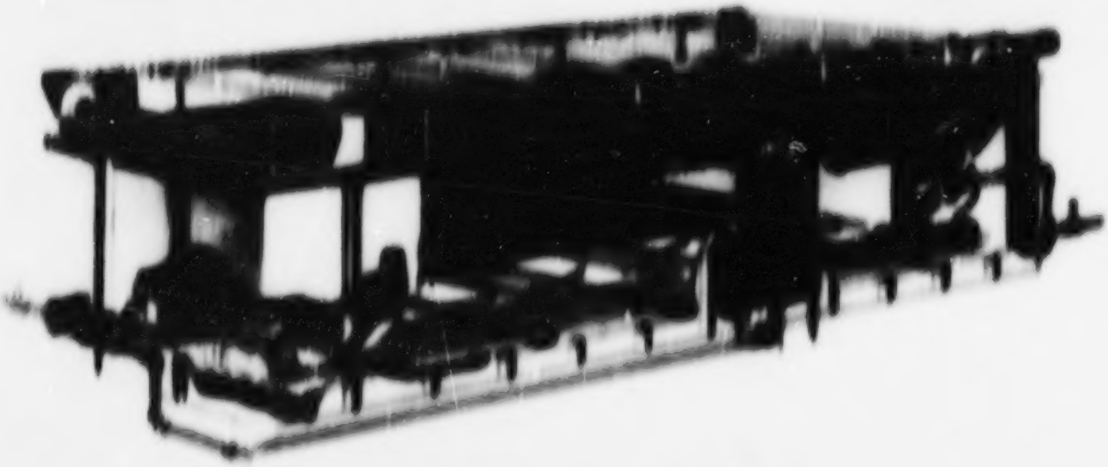
Pilot Unit

Figure No. 4



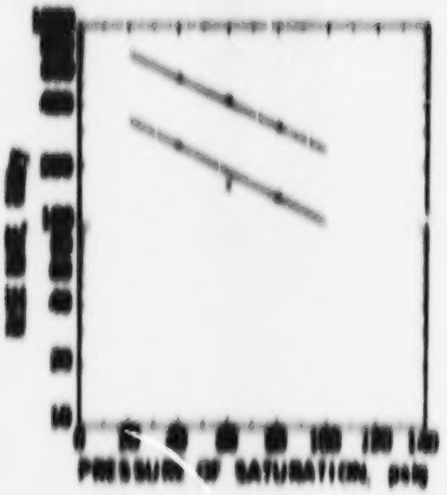
Bench Scale Testing Apparatus

Figure No. 5



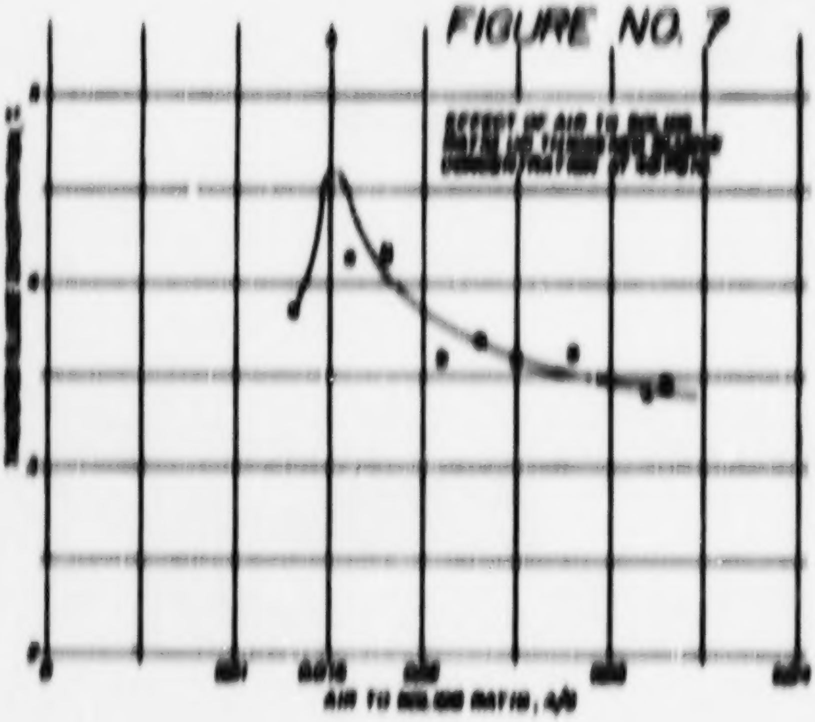
$^{1}/_{8}$ Dissolved Air Flotation Thickener

Figure No. 6



Effect of pressure on rise rate.
From R.F. Wood and R.I. Dick.

FIGURE NO. 7



THE UTILIZATION OF MUNICIPAL SLUDGE IN AGRICULTURE

By

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Raymond R. Rimkus, Chief of Maintenance and Operations
Forrest C. Neil, Chief Engineer

Presented at
United States/Soviet Seminar on
"Handling, Treatment and Disposal of Sludges"
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INTRODUCTION

The disposal of the solid residues from wastewater treatment has traditionally been the most difficult problem facing municipally and privately owned treatment facilities. In general, there exists sufficient technology to remove various pollutants from wastewater, but the disposal of the resulting solids has been a difficult technical as well as social problem.

Sludge Production

There is no known information available on the quantities of sludge currently being produced world wide. However, there are some estimates of the municipal sludge (excluding privately owned industrial wastewater treatment facilities) produced in the U.S.

Dean (1973) has estimated that the actual national production of sludge in 1972 was approximately 10,000 dry tons (9,072 metric tons) per day. The estimate is probably low since it is based only upon the sewered population and includes the effect of process variations such as digestion and incineration. By 1980, he estimated that the quantity of sludge will increase to 13,000 tons (11,800 metric tons) per day.

Extrapolation of this U.S. data to sludge quantities produced on world scale is tenuous at best since wastewater treatment is not developed to the same extent on a worldwide basis. An accurate estimate would include a study of the wastewater practices of various nations in order to arrive at even a rough estimate.

Clearly, as the nations of the world reach for higher standards of living, while preserving the quality of the environment, there will be an increasing demand for more sophisticated and advanced wastewater treatment processes. Older waste treatment practices which produced little if any solids will soon give way to practices which, in general, will generate larger quantities of sludge. Also, traditional sludge disposal techniques such as lagooning will progressively lose social acceptance and thus will require new and more innovative approaches to existing solids disposal techniques.

In addition, as the population of many nations becomes more urbanized, it will become increasingly difficult to find locations in or around large cities where sufficient space can be allocated for solids disposal. That is, wastewater solids will become increasingly out of place in relation to their point of origination.

Ultimate Sludge Disposal Alternatives

There are many combinations and variations of sludge disposal alternatives available to municipalities but the basic processes are:

1) Land Spreading
2) Incineration and Ash Disposal
3) Ocean Disposal, and
4) Land Fill

Incineration

Incineration essentially involves the combustion of the organics contained in sludge. Normally, this means that approximately 40 - 50% (dry weight) of the sludge remains in the form of ash which must be disposed of. The primary advantage claimed for incineration is that it reduces the volume of the material for disposal. However, the process requires much energy in order to burn the high water-content sludge, while the fertilizer value of the sludge is simultaneously destroyed. The process also incurs significant costs for sludge dewatering, and the ash does require a land disposal site. The incineration process also releases significant quantities of pollutants to the air including volatilized metals. Air pollution control technology for removal of metals is expensive and is not likely to meet the emerging and increasingly stringent governmental regulations. For The Metropolitan Sanitary District of Greater Chicago (District), incineration is estimated to cost from $60 - $100 per dry ton ($66.1 - $111 per metric ton) of average sludge solids excluding any costs for removal of metals and gaseous pollutants from stack gases.

The current fuel shortage has cast an additional gloomy shadow on sludge disposal by incineration. The steadily increasing cost and decreasing availability of gas and oil will affect the desirability if not the feasibility and practicality of this process in the foreseeable future.

Table 1 presents some data on auxiliary fuel consumption in seven cities of the U.S. (Olexsey and Farrell, 1974). The weighted average consumption of number 2 fuel oil necessary to burn 1 ton (.907 metric tons) of dry solids is 31.6 gallons (120 liters). If this figure is rounded to 50 gallons (189 liters) per ton nationwide and one assumes that the practice of sludge incineration were adopted nationally, then the U.S. would require at least 9 X 10[illegible] gallons (340 X 10[illegible] liters) of crude oil per year. In 1973, the nation was consuming about 50 X 10[illegible] gallons (19 X 10[illegible] liters) per year (Olexsey and Farrell, 1974). Clearly, unless alternative methods for sludge disposal are available to municipalities, sludge incineration will be at variance with the long term fuel conservation goals which many nations have adopted.

In addition to the energy required to incinerate sludge, one must also consider the fact that incineration destroys the nitrogen and other agronomic nutrients contained in the sludge. The nitrogen must be replaced and, of course, it takes energy to make the required inorganic fertilizer for replacement. For example, the replacement of one ton of nitrogen fertilizer requires 917 gallons ([illegible] liters) of crude oil. Clearly if we can recycle the nitrogen content in sludge for agricultural production, we can reduce the amount of energy required for fertilizer manufacture and the corresponding cost of food production.

Ocean Disposal

Ocean disposal offers, to coastal cities, a readily available ultimate sink for sludge. This has been practiced by many U.S. cities including Los Angeles and New York. However, this means of disposal is not available to inland cities and has many disadvantages. Any nutrient value contained in the sludge is wasted while the organics present tend to deplete the dissolved oxygen of the disposal site. Such disposal could significantly affect coastal fishing areas as well as reduce ocean bathing areas. This method of disposal has come under increased governmental scrutiny and may soon be [illegible] restricted. Costs are very low for this process and include only transportation costs although some cities are beginning to digest their sludge prior to ocean disposal.

Landfill Operations

Landfill operations are practiced by many cities and included under this general term is sludge lagooning. Landfill operations waste the organic content of sludge while considerable expense is involved in sludge dewatering either for lagoon decanting operations or prior to landfill operations. Disposal sites often are useless for other purposes following landfill and some are never returned to the tax rolls. Few sites can be used for 20 to 30 years after being landfilled with municipal sludges. Oftentimes, such sites will produce methane gas which could cause a potentially dangerous situation for other land uses.

Land Spreading

Land spreading of sludge has become a method which is being increasingly considered by many municipalities in the U.S. and indeed, throughout the world. It offers the advantage of recycling nutrients back to the land at low cost, and of reclaiming lands despoiled by strip mining. Sludge is first stabilized by anaerobic digestion or other suitable means before application on land. Such stabilization eliminates obnoxious odors and fly problems. Yields of grain and forage crops are increased by the nutrients and water supplied by irrigating with digested sludge. Digested sludge organic matter accumulates in soil and imparts favorable characteristics to soils because of its normally high humus content. The process of land spreading of sludge affords the opportunity for urban areas to recycle the fertilizer value of sludge to the farming areas from which much of the organic materials and nutrients originate. With the current shortage of fuels, and the high requirements for inorganic fertilizer production, sludge recycle for agricultural production offers a ready opportunity to reduce the energy requirements of the agricultural sector. Also, since many municipalities can offer their sludge at practically no cost to the farmer, a significant cost savings is effected both for the farmer and the municipality which produces the sludge.

SLUDGE APPLICATION TO LAND

One of the most widely publicized operations is the Rye Meads Works of the Middle Lee Regional Drainage scheme in England. Portions of the liquid digested domestic sludge produced, is taken by tanker trucks to local farms and spread as liquid referred to as "Ryganic" (personal communication with D. T. Lyman, 1974). The remainder of the sludge is dewatered on open beds and the resultant dry sludge then applied to land. The plant serves 400,000 people and a drainage area of 125 square miles (324 sq km). Approximately 60,000 gallons per day (228,000 l/day) of liquid Ryganic and about 1,000 tons (907 metric tons) per year of solid Ryganic were being applied in 1971.

Liquid Ryganic is delivered and spread free within a 7½ mile (12 km) radius of the Rye Mead Works. Because there is a large demand for liquid Ryganic during the spring and summer, customers are advised to place orders as early as possible.

Based upon the recommendations of the Hertfordshire Institute of Agriculture, liquid Ryganic is usually applied at a rate of 7,000 gallons per acre (76,500 l/ha) which contains 100 lbs. N and 115 lbs. P_2O_5 per acre (112 and 129 kg/ha of N and P_2O_5, respectively) using 1,000 gal. tankers (3785 l) spreading over an 8 ft. (2.4 m) strip. Yields of grass, barley and other crops in the area are excellent and, as noted above, the demand by local farmers is high.

The Metropolitan Sanitary District of Greater Chicago (District) has embarked upon a program to utilize the digested sludge from its treatment plants on land in the central portion of the State. Currently, the District owns over 15,000 acres (6,070 ha) of land about 200 miles (320 km) south of its 900 square mile (2,330 sq km) drainage area. Liquid digested sludge containing approximately 4% solids is barged down the Illinois River and then pumped through a 10.8 mile (17.4 km) pipeline to holding basins. During the application season which principally occurs during the months of April through October, liquid sludge from the holding basins is applied either by means of spray guns or soil incorporation. To date, rates up to 30 dry tons per acre (67.3 mT/ha) per year have been applied during the growing season to fields which were principally planted in corn.

Approximately 6,000 wet tons (5,440 metric wet tons) of 4% liquid digested sludge is currently being transported daily to the site in Illinois. In 1974, about 475 dry tons per day (431 mT) are being removed from the District's West-Southwest secondary treatment facility which currently has a design capacity of 900 million gallons (3.410 X 10^9 l) per day.

SLUDGE PROPERTIES

Sewage sludge is derived from the organic and inorganic matter removed from wastewater at sewage treatment plants. The nature of sludge depends on the wastewater sources and the method of wastewater treatment. If waste solids are to be evaluated as a soil amendment or as a fertilizer, it is important to understand their chemical and biological properties. A comparison of sludge analyses from various treatment plants would be confounded by the individual treatment processes; therefore, some of the more common wastewater treatment methods will be described.

The first treatment process is usually gravity separation of solids from wastewater. This process is commonly known as primary settling or primary treatment. Secondary sewage treatment may be accomplished by physical-chemical or biological processes. The physical-chemical processes include chemical precipitation using lime, alum, or ferric chloride. Biological secondary treatment includes trickling filters or some modification of the activated sludge process where aerobic suspended bacteria treat primary treated wastewater. These biological processes result in nutrient consumption by microorganisms and the formation of biological flocs which are later settled out and subsequently pumped to concentration chambers for further processing.

The wastewater solids separated by these primary and secondary water treatment processes may then be dried for marketing as a low analysis dry fertilizer, or subjected to various stabilization treatments. Some current sludge stabilization processes include: aerobic or anaerobic mesic or thermophilic digestion.

Following any of these latter processes the stabilized sludge may be further concentrated by drying beds, vacuum filtration, pressing, centrifuging, or lagooning with supernatant drawoff.

Some typical fertilizer value of sewage sludge can be seen in *Table 2* which gives the concentrations of the major plant nutrients from various sources in the Eastern United States. The N, P, and Ca are the dominant elements present which can aid plant growth. The storage of the processed sludge can affect the nitrogen content considerably. Peterson *et al.* (1973) reported total N and NH_4-N from an aged lagoon to average 1.6 and 1.2%, respectively. The current sludge N and NH_4-N content entering the lagoons averaged 6.0% and 3.1% respectively. The Chicago (District) sludge in *Table 2* is from a heated high rate digester and it has an NH_4-N content of 3.1%. The seven state mean presented in *Table 2* has an NH_4-N content of 0.7%.

The metal contents of sewage sludges from Chicago, seven states in the USA, and 42 locations in England and Wales (Berrow and Webber, 1972) are presented in *Table 3*. The range of metal contents is extreme in this table. It is likely that some large industrial waste loads are released into some of these sewer systems. A comparison

TABLE 1

AUXILIARY FUEL CONSUMPTION FOR SLUDGE INCINERATION IN CITIES DURING 1973

(Glancey & Farrell, News of Engr. Rec., May 9, 1974)

City	Sludge Production (dry tons/day)	Fuel/dry ton of solids[1]
Jersey City, N. J.	15	95
Providence, R.I.	30	50
Tonawanda, N.Y.	6	17
Rochester, N.Y.	17	49
Hartford, Conn.	35	140
St. Louis, Mo.	55	29
St. Paul, Minn.	275	49

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[1] Gallons of No. 2 oil

TABLE 2

Major Plant Nutrients Present in Various Sewage Sludge Sources.

Constituent	% dry wt. basis					
	Chicago MSD		Ill. 24 cities		7 States in USA[1]	
	Range	Median	Range	Mean	Range	Mean
Total N	4.5-6.6	5.6	1.6-6.8	5.0	0.03-17.6	3.3
NH4-N	1.0-3.0	2.1	0.1-6.1	1.0	0.0005-6.7	0.7
P	1.1-3.1	2.6	0.7-4.0	2.4	0.04-6.1	1.8
K	0.08-1.5	0.30	-	-	-	-
Ca	0.9-6.0	3.4	-	-	0.008-1.9	0.3
Fe	0.5-4.6	3.1	-	-	0.1-25	3.1
Mg	0.6-1.7	1.1	-	-	0.03-2.0	0.5
Na	0.2-0.7	0.30	-	-	0.003-2.7	0.4

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[1] These data are from North Central Regional Research Committee on Utilization and Disposal of Municipal, Industrial, and Agricultural Processing Wastes on Land and represent about cities in seven states

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TABLE 8

Metal Content of Various Sewage Sludge Sources.

Metal	µg/g dry wt. basis					
	Chicago MSD*		7 States in USA		Great Britain**	
	Range	Median	Range	Mean	Range	Median
Ag					5-150	20
As			6-230	43		
B			4-757	77	15-1000	50
Ba			21-8980	618	150-4000	1700
Be					1-30	5
Bi					15-100	25
Cd	180-575	197			60-1500	[illegible]
Co			1-18	6.3	2-260	12
Cr	12-4190	2000	17-99000	2620	40-8800	250
Cu	880-2270	1530	84-10400	1210	200-8000	800
Fe	19400-47000	36300	400-110000	12700	6000-62000	21000
Ga					1-20	5
Hg	0.8-7.5	3.2			[illegible]	[illegible]
La					20-100	60
Li					10-120	40
Mn	180-550	374	18-7100	400	150-2500	400
Mo			5-39	27	2-30	5
Ni	164-840	355	10-3515	406	20-5300	80
Pb	504-1160	680	13-19700	1670	120-3000	700
Sc					2-15	5
Sn					40-700	160
Sr					80-2000	500
Ti					1000-4500	2000
V					20-400	80
Y					10-100	20
Zn	1670-4850	3770	16-27800	2800	700-49000	3000
Zr					20-2000	180

*Unpublished data from Agric. Expt. Stations Committee on Utilization and Disposal of Municipal, Industrial and Agricultural Processing Wastes on Land

**Berrow and Webber. 1972. J Sci. Fd. Agric. 23:93-100

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of the metal data from Chicago, which has strict regulations on metal contents of sewage released to the sewers from industrial sources, with the seven states of the USA and Great Britain shows the effects of industrial waste regulations. The Chicago sludge has less Cr, Ni and Pb than the other seven states reported. However, in comparison to Great Britain the District sludge has a higher metal content. The continued improvement in wastewater treatment will result in a greater metal content of the resulting sludges. This is in the best interest of man in that the protection of our water resources is paramount to our future.

The residual pesticide content of sewage sludge is usually very low. Chawla *et al* (1974) reported the total organochlorine insecticide content of four cities in Ontario, Canada to range from 20 to 103 ug/l and the polychlorinated biphenyls (PCB) contents for these sludges ranged from 74 to 113 ug/l. Analyses of five wastewater treatment plants sludge sources from the District showed the PCB content to be < 50 ug/l.

The physical characteristics of sewage sludge depend on the type and extent of the wastewater treatment and the method of sludge stabilization. For example, a granular dense sludge may be produced from primary wastewater treatment, while the waste activated sludge from secondary wastewater treatment results in a sludge containing mostly bacterial cells which may be viscous and difficult to dewater. Digested waste-activated sludge has liquid properties up to a total solids content of 8 to 10%. At a total solids content of 10 - 15% this sludge is a gel which can be stirred to form a solution but reverts to a gel in a day or two. The sludge solids content must be at least 20 - 30% before it can be handled as a solid. To obtain this solids content, extended holding with good drainage and solar radiation is necessary. The pumping of sewage sludge with up to 10% total solids can be done with special techniques. Field irrigation sprinklers work best with sludge solids of up to 5 to 7%.

SLUDGE APPLICATION RATES ON LAND

Crop Production

The annual application of sewage sludge should be adequate to produce maximum crop yields. With sludges as reported in *Table 2* and *3* this translates to the nitrogen requirements of the crop. If perennial grasses are grown the annual nitrogen removal may be 300 lbs/acre (336 kg/ha). The annual N needs for corn (*Zea mays*) may be 180 lbs/acre (202 kg/ha) with good corn yields. The grass has another advantage in that it has a longer growing season and has a high water use which reduces the potential for N leaching.

As with any fertilizer system, the N content from sewage sludge is not completely available to the plants. In sludges, the NH_4 or readily available N content is approximately 40% of the total N with freshly digested material, and if the sludge has been stored in lagoons or dried on exposed beds the soluble NH_4 fraction may be 10 to 15% of the total N. The remaining sludge N is in the organic form which is mineralized in the soil at the rate of about 20 - 30% the first year and from 3 - 10% in successive years. These rates are a function of soil moisture and temperature as well as the relative stability of the sludge.

The method of sludge application also affects the N utilization efficiency. If surface application without soil incorporation, e.g. sprinkling, is used 11 to 60% of the applied NH_4-N can be lost by volatilization (Ryan and Keeney, 1975; and Peterson, *et al.* 1974). If the liquid sludge is immediately incorporated into the topsoil, about 80% of the NH_4 is retained and available for plant uptake.

The denitrification of the NO_3 and NO_2 has been estimated to be as high as 30% under moist soil conditions which are very common with liquid sewage sludge applications. These rates will vary with the placement of the sludge in the soil. No incorporation will result in the least and subsurface application will result in the highest denitrification rates.

Another means of immobilizing the nitrate is by the soil micro-flora. This can be accentuated with large additions of a high carbon source, e.g. straw, which create an accelerated growth of heterotrophic microorganisms which will consume the N. This management tool can be used to retain the soil nitrogen until the crop needs it.

The nitrogen cycle depicting the fate of sludge N as well as estimated transfer rates is summarized in *Figure 1*. As this discussion may have suggested, it is not possible to formulate uniform rules for the rate of sewage sludge application on productive land. However, if the rate is set to supply the N needs of the crop, good production can be assured.

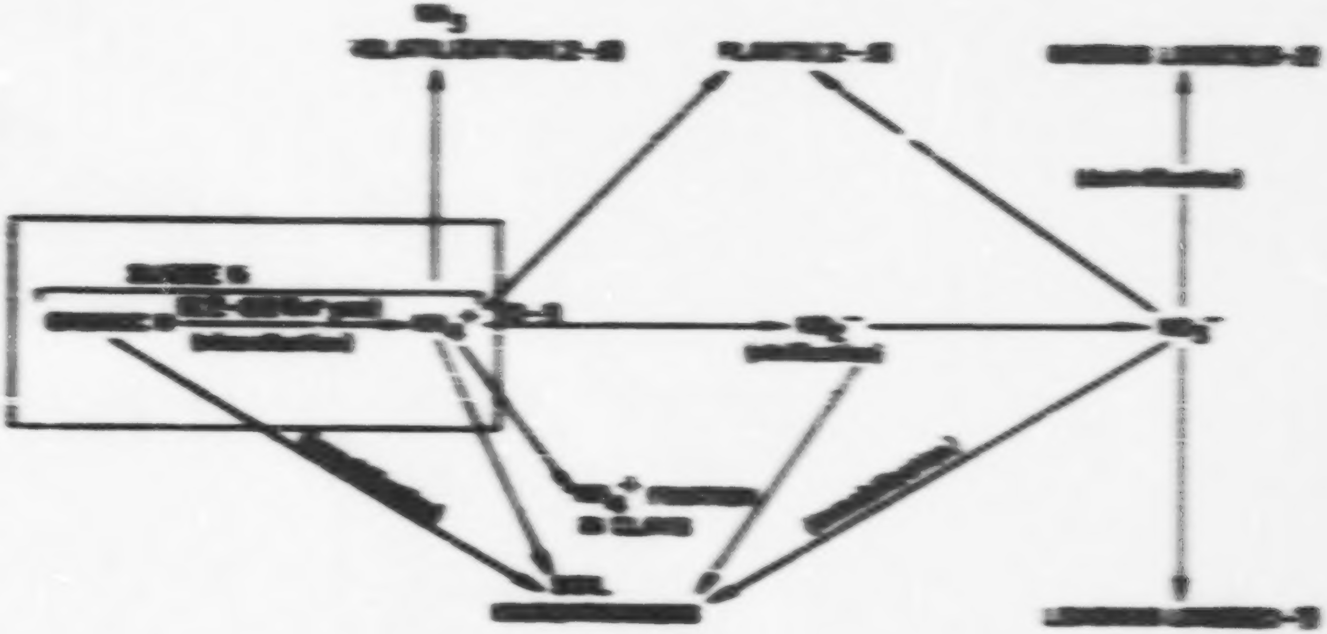
Reclamation of Spoils

The amelioration of disturbed lands, e.g. coal mine spoil, wastepits, and other unvegetated lands, has been successfully accomplished with sewage sludge (Peterson, *et al.* 1973; Lejcher and Kunkle, 1973; Sutton, 1976).

Disturbed lands usually require pH control and fertilization if revegetation is to be successful. Barren, acidic or alkali lands are very likely to have severe erosion problems. Rapid restoration of such areas is in the best interest of the area. High rate applications of

FIGURE I

N cycle illustrating the fate of sludge N with estimated transfer coefficients where appropriate. ([illegible], [illegible], with transfer coefficients added by authors)



[illegible]

[illegible]

SITE SELECTION, DESIGN & MANAGEMENT

Topography & Soil Factors

Site development should be based on the following four sets of parameters for environmental control:

1. The site plan should be developed so that it would not cause air, land or water pollution now or in the future.
2. The site plan should implement the principle that organic solid material from urban areas is not a waste product to be discharged but rather a valuable organic material to be recycled for beneficial use.
3. The plan should be developed to provide a [illegible] with [illegible] development.
4. The site should be developed in close liaison with environmental regulatory agencies to insure maximum protection of the natural environment.

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

Because the key to successful development is the control of water on the District's site, the District set up a program that involved:

1. An initial hydrological survey and complete log of existing water quality data;
2. The design and construction of an [illegible] system, the holding reservoirs, and the [illegible] system; and
3. Establishment of an ongoing identification of water quality for local, state, and federal review.

Site Preparation

Prior to sludge application on the District's site each [illegible]

Illinois water quality standards. In addition, several small streams that run through the property are monitored at points where they enter and leave District property. The United States Geological Survey, Illinois Environmental Protection Agency and the Fulton County Health Department also monitor some of these streams as well as several other locations within the property.

Numerous shallow wells have been located throughout the property for purposes of supplying groundwater for monitoring purposes. Shallow wells for groundwater monitoring purposes surround the sludge holding basins that were put into operation first. Extensive use of grassed waterways reduces the sediment load that leaves the fields during heavy rains. These waterways also provide for additional utilization of nutrients prior to entry of the runoff into retention basins.

Site Management

The basic aim of the District is to be able to apply as much sludge to a particular location as the environmental limitations will permit for rapid restoration of productivity. In this regard, an agricultural cropping program is a vital component. To date, the District has contracted with local farmers for completely caring for most field crops from planting on through harvest. Most users in the United States, utilizing sludge as soil fertilizer, have the agricultural cropping done by local farmers.

Sludge is applied at the District's site by using contract employees to operate District owned application equipment. Supervision of contract employees is done by a small permanent District staff who reside in the vicinity of the application site. Transportation of sludge to the District's land utilization site is entirely done by a private contractor who uses river barges and pipeline.

Throughout the United States, many combinations are used for sludge transportation, site application and site management. Most small sanitary districts either transport sludge to the site by truck and apply it or permit farmers to haul sludge to their own application site. Usually, most site management involving agricultural operations is done by local farmers. Because of increased governmental agency environmental consciousness, there has been a definite trend, in the United States, toward land utilization of stabilized sludges. Utilization can be either for land reclamation or fertility utilization by conventional agricultural crops.

Public Relations

One of the greatest difficulties with implementing land utilization or disposal programs for sludge in the United States has been with public acceptance. The general public is not sufficiently aware of the nature of stabilized sludges so that a rational consideration of such programs seldom occurs. This problem becomes more acute when large projects are proposed in rural areas.

An educational program would appear to be a necessary and integral part of any large scale land utilization program. It does not appear sufficient to stress the value of the material relative to its nutrient and organic matter content. The public needs to be more fully informed of the product stability and lack of public health risk, odor potential and water contamination potential so that unfounded anxieties may be relieved.

The land disposal site, be it utilization, landfill or reclamation, can be operated to minimize problems to the public sector. Only well stabilized material should be brought to the site to prevent odor and vector problems. Storage and application operations should be conducted in such a manner as to prevent loss of the material which occurs primarily through water movement. In land utilization systems, tillage of the applied solids into the soil at an early date has a positive effect on odor control and in reduction in the possibility of contaminated surface runoff. Good housekeeping practices can produce effective results.

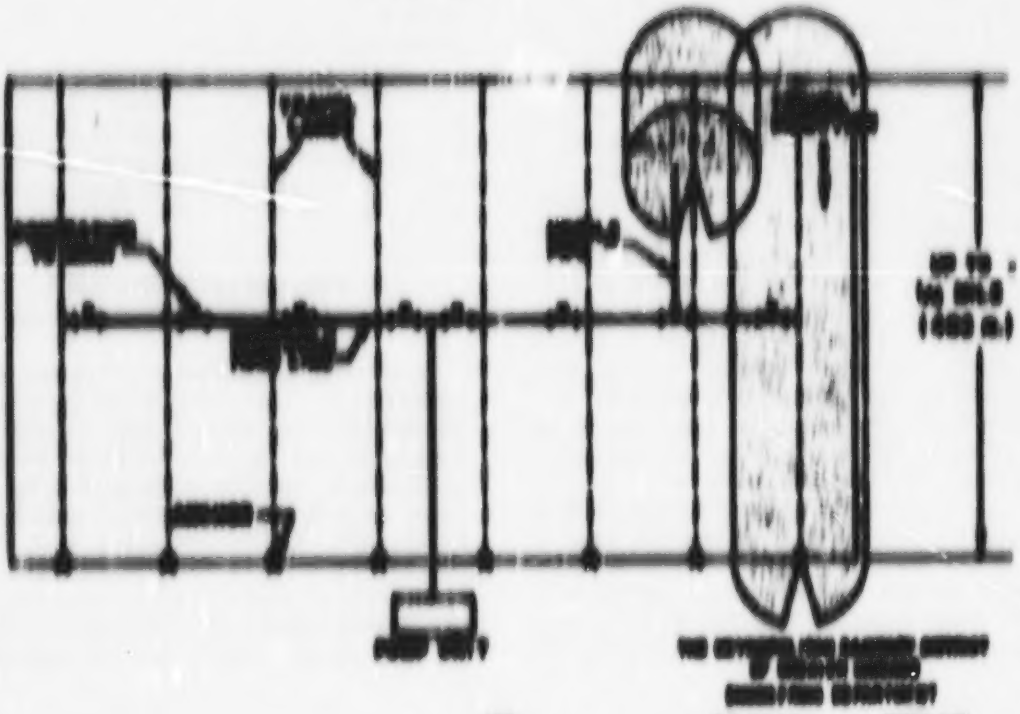
IRRIGATION SYSTEMS

When large volumes of liquid sludge are to be applied to established crops, several application methods can be used. *Figure [illegible]* shows a traveling sprinkler with a single nozzle volume gun. Nozzles range in size from [illegible] to [illegible] inches ([illegible] to [illegible] mm) for sludge application. Nozzles must be operated with sufficient pressure to break the liquid stream into very small drops to avoid damage to the crop and soil. Practices which are recommended for irrigating water with traveling sprinklers also apply for sludge irrigation.

Figure [illegible] shows a typical layout for a traveling sprinkler. Width of a single pass depends upon nozzle size and pressure but is normally [illegible] to [illegible] feet ([illegible] to [illegible] m). The mobile pipe or hose is commercially made up to five inches ([illegible] cm) in diameter and in lengths of [illegible] feet ([illegible] m). Propulsion across the field is accomplished by a small engine which drives a winch to wrap up an anchored cable. Application travel speeds are in the order of several feet per minute but can be varied to suit field conditions. When one pass is completed the hose is disconnected, emptied of sludge and then wound on a reel for transport to the next lane of application. A small tractor is sufficient for moving the sprinkler and hose reel and a crew of two is adequate for

Figure 11. Traveling sprinkler applying liquid sludge to a corn crop.

FIGURE 12


PUMP UNIT
UP TO 1/4 MILE (400 m)

operating a traveling sprinkler. The most predominant problem with large-sized nozzles for sprinkler application has been with downwind drift of small droplets.

Liquid sludge can also be applied by center-pivot irrigation machines to growing crops. Actual operation of these machines for sludge application has been relatively limited at this time in the United States. The same range of nozzle sizes that were used on traveling sprinklers can also be used for center-pivot machines. Some opportunity is present for development of a low pressure application device in conjunction with the center-pivot machine. The main reason for interest in low pressure application is in reducing spray drift. The primary advantage of the center-pivot machine is in the reduction of operational labor. When in conventional use for applying irrigation water, center-pivot machines operate unattended for long periods of time; motive power is supplied by electrical motors.

Combinations of ridge and furrow, gated pipe and flooding systems have been used to apply sludge to fallow lands or fields with growing crops. Regardless of the application method, excessive liquid sludge should not be applied because of possible deleterious effects of water logged crops and environmental contamination.

Soil Incorporation & Injection Systems

In the past several years in the United States, incorporation devices have been developed which mix liquid sludge into the soil. Injection devices have been used for a number of years to place liquid livestock manure beneath the soil surface and are now being used for municipal sludges. The distinction between these two methods is in the narrow sense, but in addition, an incorporation device (usually a conventional agricultural disk harrow with attached sludge distribution manifold) applies sludge to the entire cross-sectional area of the soil being tilled whereas an injector usually applies sludge in bands or slots formed in the soil by a tool (knife). Most injectors use self-contained tanks for the liquid while incorporation devices use a feeding hose similar to a traveling sprinkler. However, either device could use either method for sludge supply.

Incorporation devices place the sludge into the soil where it is less subject to erosion and runoff than surface application. Offensive odors can be more completely controlled by placing sludge quickly into the soil. While incorporation devices destroy all vegetative cover, an injector can apply to a grass sward without serious damage to the grass. Both devices need large tractors to operate at any reasonable flow rate. Figure 17 shows an incorporation disk while Figure 18 shows an injector.

Slurry, Cake and Solids Handling Systems

Most of the problems associated with handling of municipal sludges are related to their physical properties. Slurries can be handled with pumping equipment and pipelines; however, the viscosity of such sludges may result in pumping difficulties. In stabilized liquid sludges, pump problems are sometimes encountered with entrained gases formed during decomposition. These gases enter the pump suction line and loss of prime or cavitation is often observed. Problems such as these should be considered in initial design.

High viscosity of slurries causes a considerably greater variation in pipeline pumping losses as the pipeline length changes, as compared to lines conveying water. Pump and pipeline transfer systems can presently convey sludges with up to 12-15% sludge solids content. Technological improvements are likely to increase these limits. Presently, the limitation on solids content for applying sludges by high pressure, large volume nozzles appears to be between 7 and 8%. Systems using smaller nozzles and lower pressures are more restricted in handling the solids without blockage.

When transporting dry sludges, one cannot depend upon friction, gravity or inertia, when used in conjunction with conveying devices, to move the solids to where they are intended to go. The adhesive nature of sludges at various moisture conditions might cause the sludge to stick in the conveying device. Solid sludges are usually spread by conventional manure spreaders while loading is readily done with end loaders.

Liquid sludges contain abrasive components such as sand and other inert materials which will wear on pump shaft bearings and must be considered in pump design. Corrosion problems, related to conveying of sludges, are usually not significant because sludge has nearly a neutral pH.

SOIL AND CROP RESPONSES TO SLUDGE APPLICATION ON LAND

Sewage sludge when applied to soils provides a readily available source of plant nutrients and it is an effective soil amendment. The chemical quality of sewage sludges is dependent upon wastewater sources and the methods of wastewater treatment as discussed earlier in the section on sludge properties. Sludges applied to land provide major plant nutrients such as N, P, K, micro plant nutrients such as Cu, Fe and Zn and organic matter for improving the soil structure (e.g., better aeration and water holding capacity). The effectiveness of sludge as a soil improving agent depends upon the composition of

Figure IV. Disk incorporation with trailing supply hose.

Figure V . Injection unit showing three injectors.

[illegible]

[illegible]

Crop Types

[illegible]

[illegible]

Crop Responses

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

TABLE [illegible]

Corn yields from 1968 through 1973 [illegible]

[illegible]	[illegible]	Year					
		1968	1969	1970	1971	1972	1973
[illegible]	[illegible]	Corn - Yield metric tons/ha at 15.5% moisture					
Check	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

TABLE [illegible]

Total maximum annual application of digested sludge [illegible]

Year	Liquid Sludge	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]
1968	[illegible]	[illegible]	[illegible]	[illegible]
1969	[illegible]	[illegible]	[illegible]	[illegible]
1970	[illegible]	[illegible]	[illegible]	[illegible]
1971	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]
1972	[illegible]	[illegible]	[illegible]	[illegible]
1973	[illegible]	[illegible]	[illegible]	[illegible]

[illegible]

[illegible]

TABLE 6

[illegible]

Year	[illegible]			
	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]			
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Average	[illegible]	[illegible]	[illegible]	[illegible]

[illegible]

TABLE 7

[illegible]

Year	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

Metal Translocation

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

ANIMAL RESPONSES

An excellent use of the fertilizer value of municipal sludge is its application to pasture land. Excellent stands of forage crops can be produced from the nutrients and organic content of municipal sludge.

TABLE 9

Soybean yield response to phosphorus, sludge and water applications (Unpublished data, Illinois, et al).

Year	P kg/ha	Rate of Sludge Application				Water a/
		0 cm	[illegible] cm	[illegible] cm	[illegible] cm	
		Yield (metric ton per hectare)				
1969	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	110	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1970	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	110	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1971	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	110	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1972	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	110	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1973	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	110	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

a/ Water application rates were the same as the equivalent sludge rate and were applied on the same day

TABLE 10

Average contents of several chemical elements in tissues of soybeans fertilized with various loading rates of digested sludge. Values are ppm dry weight of plant tissue (Unpublished Data, Illinois, et al).

Year	Leaf and Petiole					Seed				
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]										
1970	[illegible]	--	[illegible]	--	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1971	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1972	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1973	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]										
1970	[illegible]	--	[illegible]	--	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1971	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1972	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1973	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]										
1970	[illegible]	--	[illegible]	--	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1971	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1972	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1973	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]										
1970	[illegible]	--	[illegible]	--	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1971	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1972	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1973	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

TABLE 9

Average contents of several chemical elements in tissues of corn continuously grown and annually fertilized with various loading rates of digested sludge. Values are ppm dry weight of plant tissues (Unpublished Data, Hinesly, et al).

Year	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]

* Significant at 5% level
** Significant at 1% level

LSD's:

[illegible]

N.S. = not significant

In experiments performed by Fitzgerald and Jolly (1974), where Sudax grass was fertilized by means of the spray application of liquid digested sludge from the Metropolitan Sanitary District of Greater Chicago, it was found that such grass contained 7.80% to 23.01% protein, 20.67% to 37.00% fiber, 0.43 to .074 calcium, 0.39% to 0.44% potassium, 0.01% to 1.31% nitrate, and was negative for cyanide and arsenic. Dehydrated sorghum-sudan grass was found by Schneider (1974) to average 15.5% crude protein, 9.7% digestible crude protein, 19.4% crude fiber and 58.0% total digestible nutrient. Sudax is a sorghum–sudangrass hybrid, and the quality of sludge fertilized Sudax compared favorably with that tested by Schneider. Fitzgerald concluded that sludge fertilized forage contained a sufficiency of those elements known or believed to be essential to animal nutrition.

Clearly, if municipal sludge is a satisfactory fertilizer for many crops, it should be useful in fertilizing forages. The Fitzgerald study confirms this basic premise.

Of concern to some individuals regarding the use of sludge fertilized forage for animal feed is the possibility of problems with animal health. Naturally, the grazing animals will have direct contact with the sludge while they are grazing. This is not to say that grazing animals should come into contact with municipal sludge immediately following application. On the contrary, it is advisable to allow an 8 to 10 day resting period following sludge application to pastureland or alternatively that the applied sludge be allowed to dry before resuming grazing.

The Board of Works Sewage Farm at Werribee, Australia was established in 1897 as a sewage farm serving the City of Melbourne, Australia which has a population of about 2.5 million people (Johnson et al., 1974). The daily amount of raw sewage arriving at the farm vary but the average flow in 1973 was 144 MGD (545,000 m³/day). This farm is about 10,376 acres (4,200 ha) and is a raw sewage irrigated pastureland. The irrigated pastures are sown with a mixture of grasses and legumes to provide balanced production. Raw sewage is applied in a flood irrigation method to a depth of 4 inches (100 mm). Just before irrigation, the grazing animals are removed and the surface is allowed to dry one week before they are returned.

Despite the fact that the pasture is irrigated with essentially raw sewage, the health of the animals bred at the farm is excellent and there is no prohibition of the sale of the animals for human consumption. Between July 1960 and June 1973, out of a total of 110,388 animals marketed there were only 20 rejections or 0.018%. In an Australian area where pastureland is used with no sewage products, namely, Victoria and Tasmania, a rejection rate of .041% was recorded based on examination of 500,835 animals and 208 rejections.

Clearly, the Australian data indicate that if there is no difficulty in the rejection rate of animals foraging on pastures fertilized with raw sewage, one can conclude that there should be no difficulty with the use of digested sewage sludge.

Fitzgerald and Jolly (1974) studied the possibility of transmission of parasitic organisms from digested sludges sprinkled on Sudax grass to cows and/or calves. In this study, 91 pregnant Hereford-Angus-Charolais cows were released on municipal sludge fertilized Sudax pasture. The sludge being liquid digested sludge from the Metropolitan Sanitary District of Greater Chicago. A control herd of 19 pregnant cows were pastured on Sudax in a land area not receiving digested sludge.

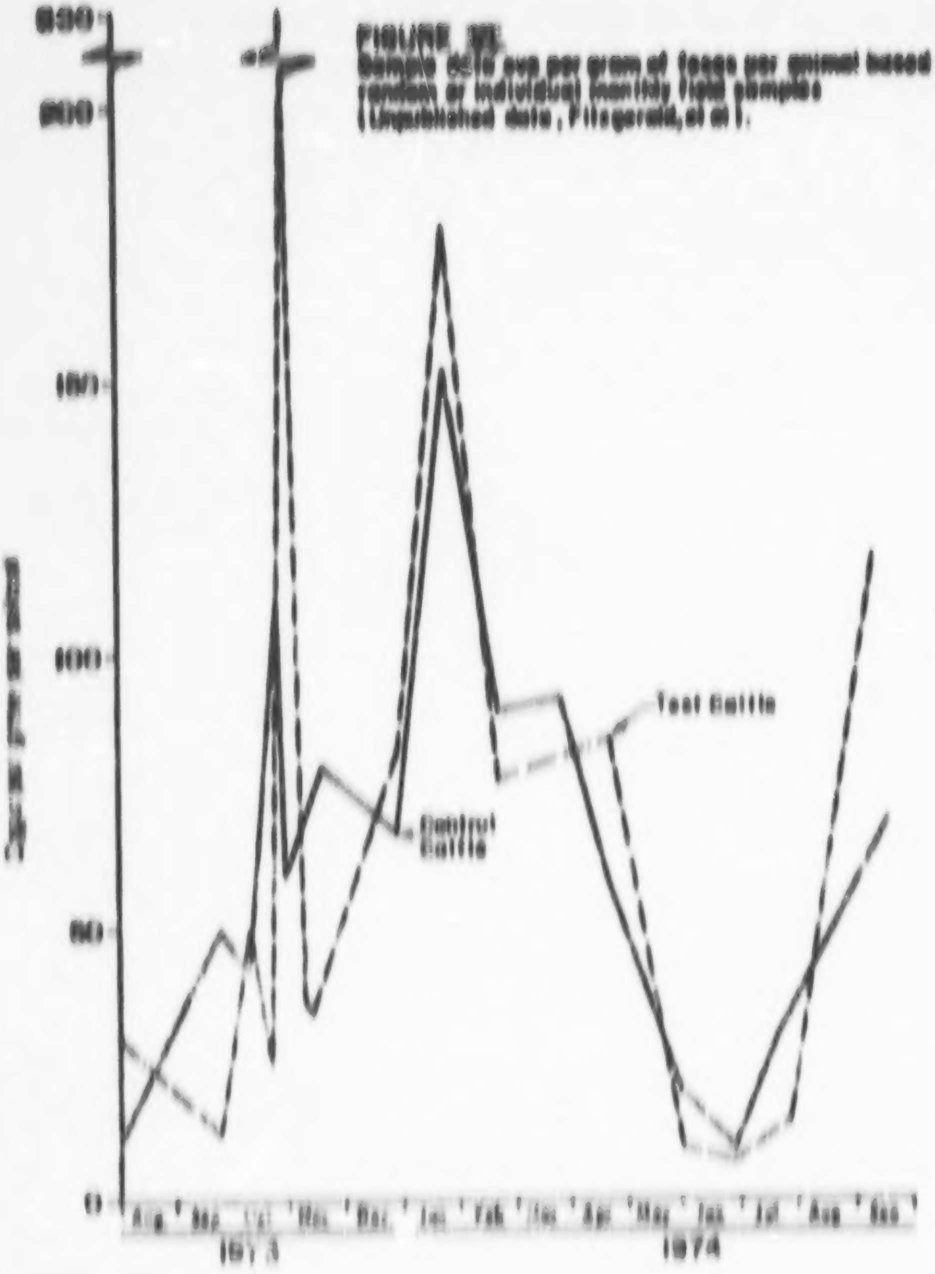
At monthly or shorter intervals fresh individual or random fecal samples were examined to determine the species and relative abundance of parasites of each herd. In addition, frequent visual observations of the animals were made. A comparison was made of the parasite species present, egg and oocyst discharge quantity, and visual clinical signs between the 2 groups of animals to determine the effects of sludge on the health related factors in the pasture environment.

After the examination of 614 fecal samples from the cattle foraging on the sludge fertilized pasture and 215 samples from the control herd, it was found that there was no significant difference between the two groups. In *Figure VI* is plotted the nematode egg discharge during 14 months of the study. Generally, the test and control herds followed a similar pattern with levels of nematodes remarkably similar. The average discharge of coccidian oocysts seen in *Figure VII* was actually higher in the control than the test animals over a 14-month period.

Fitzgerald and Jolly (1974) concluded from this study that sludge irrigation had not introduced unusual or additional common bovine pathogens to the pasture environment, nor otherwise increased the incidence of common bovine disease. Digested sludge in the pasture environment had not influenced the normal parasitic load of the herd.

The available evidence indicates that the use of municipal sludge as a fertilizer for pastureland is a practice without hazard to the health of the grazing animals. There is no available evidence to suggest that the health of grazing cattle would be affected. It would appear that many countries in the world would wish to pursue the use of municipal sludge in growing forages for cattle production. As the demand for meat increases among the nations of the world, and with the increasing problems of obtaining fuel for producing sufficient nitrogen fertilizer, it would seem that municipal sludges

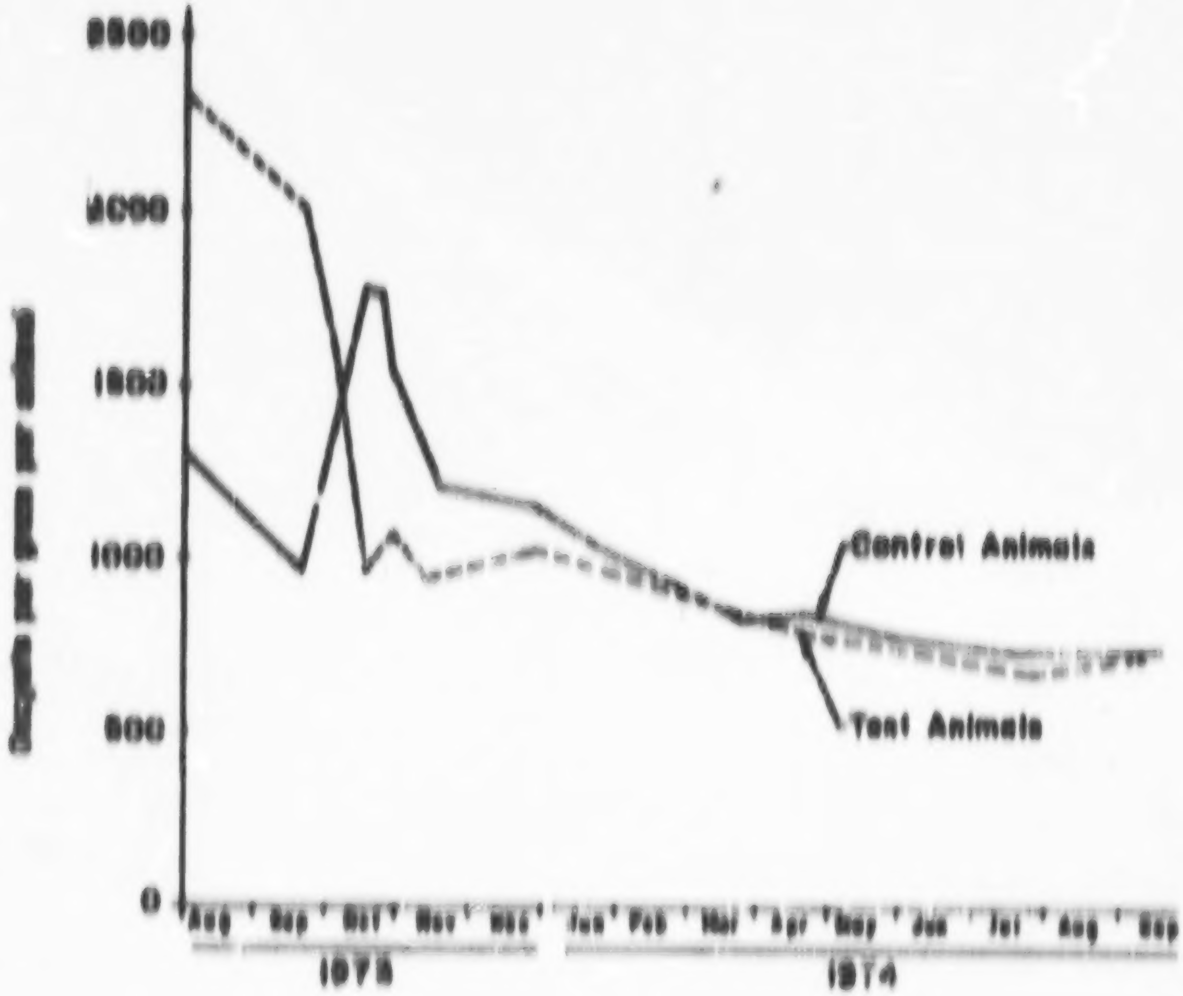
FIGURE [illegible].
Sample data eggs per gram of feces per animal based on random or individual monthly field samples (Unpublished data, Fitzgerald, et al).



THE METROPOLITAN SANITARY DISTRICT
OF GREATER CHICAGO
ENGINEERING DEPARTMENT

FIGURE XII

Cumulative total coccidian oocysts per gram of feces per animal based on random or individual monthly field samples (Unpublished Data, Fitzgerald, et al).



THE METROPOLITAN SANITARY DISTRICT
OF GREATER CHICAGO
ENGINEERING DEPARTMENT

BY W.B. MAR. 1975

would be a useful product in increasing the productivity of the pastureland.

ENVIRONMENTAL MONITORING OF SLUDGE APPLICATION TO LAND

As noted previously, the land application of sewage sludge is practiced extensively in the United States and many countries throughout the world. Cities such as Melbourne have operated "sewage farms" to dispose of sewage for many decades. Even though sludge is beneficial as a fertilizer and soil amendment, its application to land must not result in significant degradation of local waters and the soil ecosystem.

The term monitoring is defined by Nicholas (1973) means observing the performance of the system, checking the quality of affected natural systems such as surface and groundwaters and evaluating environmental impacts as quality changes occur. In short, the information obtained from monitoring should be consistent with the changes expected or predicted to occur during the design of a land application system.

The type of monitoring program employed depends to a great extent on the size and purpose of the project. Large scale land application systems would require extensive monitoring of the environmental components at a high frequency, while small scale projects would require less extensive monitoring at less frequent intervals. However, all projects need to assess the quality of sludge applied and the impact of sludge on the quality of surface and groundwaters and on the soil plant system at some prescribed frequency.

In any sludge application system, the quality of surface and groundwater needs to be assessed before, during and after sludge applications. Guidelines and suggestions for water monitoring of land application systems in the United States are available from the Environmental Protection Agency and from state regulatory agencies.

As mentioned earlier, the District is currently recycling sewage sludge on approximately 15,000 acres (6,070 ha) of calcareous strip-mined land in West Central Illinois. A comprehensive environmental monitoring system was developed in 1971 and is being used to continuously evaluate the surface and groundwater quality at the site. The District started collecting water quality data from 1971 to the present at monthly intervals. This included sampling of major streams entering and leaving the property and strip-mined reservoirs. It should be noted that this is a large scale project and that smaller projects would require less extensive monitoring.

The chemical-physical-biological quality of surface waters (streams and strip mine reservoirs) at the District's Fulton County, Illinois land reclamation site is monitored on a monthly basis for the 25 chemical parameters that shown in Table 11. In addition to fecal coliform counts determined in each stream and surface water body monitored, stream flow levels are also measured on a monthly basis on major streams entering and leaving the property.

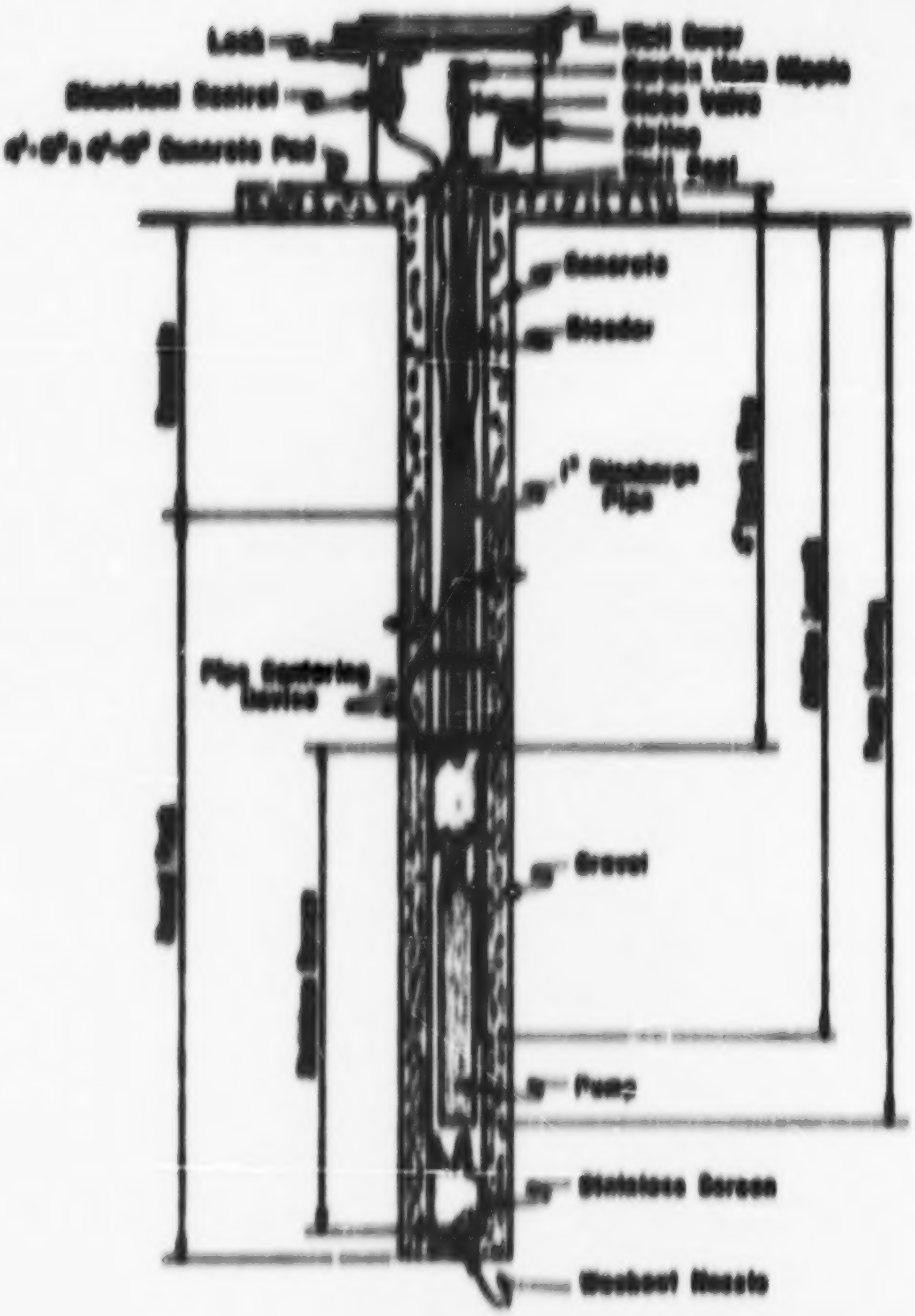
In addition, each agricultural field is bermed and drained into a field runoff basin to prevent direct runoff into the local waterways. These basins are designed to capture and contain from the adjacent field receiving sewage sludge. The basins are designed to capture runoff from an equivalent 100-year storm in the region. Any possible contamination to the field runoff water resulting from sewage solids applied to the field are also captured and contained by these basins.

Samples from the field runoff basins are analyzed to determine the percent suspended solids, biological oxygen demand and fecal coliform concentrations of their content. If the concentrations of these water quality parameters are within acceptable limits set by the Illinois Environmental Protection Agency, the contents of the field runoff basins are discharged to the receiving stream. If the concentrations are not acceptable, the contents of the field runoff retention basin may be held until sufficient reduction of the offending constituent is attained or, at the discretion of the project manager, may be pumped back on to the field serviced by the field runoff basin in question. Good soil conservation practices on the application fields are essential in reducing field runoff problems and maintaining the water quality requirements of field runoff basins needed for release. Groundwater monitoring is also an important part of a monitoring system on lands receiving sewage sludge. Groundwater monitoring wells or periodic deep soil corings are used to monitor groundwater quality. Nicholas (1973) indicates that monitoring wells must be designed and located to meet the specific geologic and hydrological conditions at each site. Groundwater quality should be monitored in the upper most water table near the application site. Consideration must be given to the following:

1. Geological soil and rock formations existing at the specific site.
2. Depth to an impervious layer.
3. Direction of flow groundwater and anticipated rate of movement.
4. Depth to seasonal high water table and an indication of seasonal variations in groundwater depth and direction of movement.

MONITORING WELL AT LAND RECLAMATION SITE
FULTON COUNTY, ILLINOIS

FIGURE [illegible]


Lock
Electrical Control
4'-0" x 4'-0" Concrete Pad
Well Cover
Garden Hose Nipple
Globe Valve
Airline
Well Seal
Concrete
Bleeder
1" Discharge Pipe
Pipe Centering Device
Gravel
Pump
Stainless Screen
Washout Nozzle

[illegible]

Sample Analysis

Those samples collected for background water quality should be analyzed for [illegible]

1. [illegible]
2. Specific Conductance
3. pH
4. Total hardness
5. Alkalinity
6. (a) [illegible] nitrogen
   (b) [illegible]
   (c) [illegible]
7. Total phosphorus
8. Methylene blue active substances
9. Chemical oxygen demand
10. Any heavy metals or toxic substances found in the applied wastes.

After adequate background water quality information has been obtained, a minimum of one sample per year, obtained at the end of the irrigation season (in the case of seasonal operation), should be collected from each well [illegible]

[illegible] analyzed for the other parameters listed above to determine the extent of water quality deviation from background levels.

Soil and Vegetation

In any land application program a systematic sampling of soil and vegetation is desirable. The objective of monitoring for soils and plants is to evaluate and prevent the possible buildup of components added to the soils which may result in plant toxicity and human food chain accumulation. Of particular concern are the so-called heavy metals in sewage sludges.

A review of the possible fate and effects of trace elements in sewage sludge when applied to agricultural lands has been made by Leeper (1972) and Page (1974). A discussion of soil-plant relationships as related to applications of municipal sludge on land is given by [illegible] (1973). Heavy metals of major concern in soil monitoring considered to be a potential hazard to plants in the food chain are: B, Cd, Cr, Cu, Hg, Ni, Pb and Zn. Of these Cu, Ni and Zn are considered by many researchers (Chaney and [illegible], 1976; Leeper, 1972; and Page, 1974) to have the greatest potential to cause phytotoxicity in plants.

It should be noted, that District field research data with corn and soybeans from 1968 to date indicates that if sewage sludge is applied to soils at an annual rate consistent with the yearly nitrogen requirements of the crop, and if sludge is applied at a total accumulative rate based on the sludge phosphorus levels then heavy metals problems in the food chain and plant phytotoxicity will not occur.

In monitoring the effects of applying municipal sludges on the soil two approaches are possible, or they can be used together. Melsted (1973) indicates that one approach is to make a systematic soil analysis and the other is to make a systematic plant analysis. Soil analysis requires that the analytical values be correlated to plant composition so that dependable predictions of plant composition can be made. Plant analysis requires that the normal composition and upper tolerance level be known and set for an indicator plant or the crop grown at the land application site. Typical ranges in soil metal composition is given by Bowen (1966) and Swaine (1955). Melsted (1973) in *Table 11* shows the probable available form, average composition range for selected agronomic crops and suggested tolerance level of heavy metals in agronomic crops. In any land application system, evaluation of the heavy metal content of soils and/or plants before sludge application is essential to evaluate future buildup of metal levels.

To determine the effect of sludge application on land, the District at its Hanover Park, Illinois research farm and its 15,000 acre (6,075 ha) mine-spoil reclamation site conducts yearly sampling of soils and crops. As an example, the metal content of corn leaves grown in 1972 and grain grown in 1972 and 1973 at the Fulton County, Illinois land reclamation site is presented in *Table 12*. The summaries are grouped by non-sludged and sludge fertilized fields. The metal and organic carbon content of spoil banks and plane lands of the reclamation site are presented in *Table 13*.

It should be noted that if sludge is applied to lands growing crops not in the human food chain trace element uptake would not be a significant consideration. In the case of cotton or trees for example, there would be little need to monitor the metal contents of these plants since the crop grown is not ingested directly or indirectly by humans.

The extent of soil and crop monitoring depends upon the type and scale of a land application system. For small land areas receiving sludge as a fertilizer the Ontario, Canada Ministry of the Environment (1972) suggests periodic soil sampling to measure soil pH for possible liming and P, K, Mg, and [illegible]. Each crop on treated land should be analyzed for N, P, K, Ca, Mg, Mn, Fe, Cu, Zn, and B. The sludge used should be analyzed at least every three months for total solids, volatile solids, pH, N, P, K, major cations and heavy metals.

Public Health Aspects

In any operation where municipal sludge is applied to the land, there will be public concern regarding the possibility of disease transmission to the surrounding population. Although no exhaustive epidemiological study has been done on a municipal sludge application project, there exists much peripheral information which indicates that such public health problems are not significant.

Normally, in the spreading or application of sludge to land, one must expect that aerosols will be generated. Agitation by the wind and/or application equipment is inevitable.

Studies by (Ledbetter *et al.*, 1973; Ledbetter, 1973) indicated that workers at sewage treatment plants had no more incidence of respiratory disease than similar workers at other sites. Absenteeism among sewage plant workers was found to be lower than among all other occupational groups studied by Melnick (Melnick, 1967).

The above three references indicate that although sewage plant workers are exposed to aerosols from activated sludge aeration tanks which contain only partially treated sewage, they are not subject to higher disease incidence than among other industrial groups. It should be remembered that sewage plant workers are in very close proximity to such aeration tanks, while in a sludge application operation, local inhabitants would be located at much greater distances and would not be exposed to or be in contact with the application operations. It may therefore be concluded that aerosol disease transmission from municipal sludge application is not a significant consideration.

There is other indirect evidence to suggest that disease transmission is not a significant problem with municipal sludge application sites.

It is a well known fact that anaerobic municipal sludge digestion is a highly effective process in coliform reduction. This is in fact, one of the benefits of such digestion which is pointed out in such standard textbooks as Fair and Geyer's (1963) *Elements of Water Supply and Wastewater Disposal*. Clearly, anaerobic digestion reduces the pathogens present in sludge as indicated by the coliform reduction. Normally, coliform

TABLE 11

The chemical-physical-biological characteristics determined in surface and ground waters of the Fulton County Land Reclamation site.

		[illegible]
pH		
Total P	mg/l	0.01
Cl^-	mg/l	1.0
SO_4	mg/l	1.0
N-Kjeldahl	mg/l	1.0
$N-NH_3$	mg/l	0.1
$N-NO_2 + NO_3$	mg/l	0.01
Alk as $CaCO_3$	mg/l	1.0
Conductivity	µmhos/cm	
K	mg/l	1.0
Na	mg/l	1.0
Ca	mg/l	1.0
Mg	mg/l	1.0

		[illegible]
Zn	mg/l	0.1
Cd	mg/l	0.01
Cu	mg/l	0.01
Cr	mg/l	[illegible]
Ni	mg/l	0.1
Mn	mg/l	[illegible]
Pb	mg/l	[illegible]
Fe	mg/l	0.1
Al	mg/l	1.0
[illegible]	mg/l	[illegible]
Hg	µg/l	0.1
Fecal Coliform per 100 ml		[illegible]

[illegible]

TABLE 12

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

TABLE 15

METAL CONTENT OF CORN LEAVES AND GRAIN HARVESTED ON [illegible] LAND IN FULTON COUNTY, ILLINOIS BEFORE AND AFTER SLUDGE APPLICATION

SAMPLE SOURCE AND YEAR	N	Mg	Ca	Na	Zn	Fe	Mn	Cu	Ni	Cr	Pb	Cd*
	%	%	%	MG/KG DRY WT.								
LEAVES-1973												
NON SLUDGED	1.8	0.20	0.21	100	10	207	20	10.7	7.0	1.7	0.0	1.0
SLUDGE FERTILIZED	1.9	0.20	0.40	510	20	204	20	27.7	0.7	NA	NA	0.1
GRAIN-1973												
NON SLUDGED	0.17	0.10	0.005	47	NA	40	10.0	0.0	NA	NA	NA	NA
SLUDGE FERTILIZED	0.21	0.10	0.005	11	NA	40	0.0	0.0	NA	NA	NA	NA
[illegible]-1973												
NON SLUDGED	0.01	0.10	0.007	20	24	20	7.0	0.0	0.0	0.1	0.0	0.1
SLUDGE FERTILIZED	0.20	0.10	0.07	20	11	20	0.1	0.0	0.0	0.0	0.0	0.0

*IN THE ANALYSIS

TABLE 16

METALS, EXCHANGEABLE CALCIUM AND ORGANIC CARBON CONTENT OF SPOIL MATERIAL AND PLACID LANDS IN FULTON COUNTY PRIOR TO THE APPLICATION OF DIGESTED SLUDGE SAMPLES COLLECTED IN THE SPRING OF 1973

SITE SAMPLED	Mn	Zn	Cu	Cd	Cr	Ni	Pb	Al	EXCH. Ca	ORGANIC CARBON
	MG/G OF OVEN DRY SOIL								%	%
SPOILS										
MEAN	184	21.7	4.70	0.0	1.00	8.7	0.00	000	0.03	0.01
MINIMUM	70	11.1	1.00	0	0	0.0	0	004	0.00	0.01
MAXIMUM	200	20.4	10.1	1.00	0.10	10.0	0.00	020	1.10	1.00
PLACID LAND										
MEAN	100.1	21.4	0.00	0.00	1.00	7.0	4.00	040	0.00	1.04
MINIMUM	21.0	10.0	1.00	0	0.00	0.0	1.00	017	0.00	0.00
MAXIMUM	200.0	20.7	0.70	0.00	0.17	10.7	7.04	701	0.70	1.00

* THREE SUCCESSIVE 5 MINUTE EXTRACTIONS OF 10 GRAMS SOIL WITH 15 MILLILITERS OF ACID

reductions over 99% are reported for anaerobic digestion.

Recently, virus levels in sludge are of concern to many. In addition to bacteria, [illegible] [illegible] [illegible] regarding the die-away of viruses in digested sludge, there is [illegible] [illegible] regarding the die-away of viruses seeded into digested sludge.

The District has conducted two studies designed to investigate the reduction in virus levels in digested sludge.

In the first study (Bertucci *et al.*, 1974) the coliphage or bacterial virus (MS-2) was inoculated into pilot anaerobic digesters. It was found that between 97.7 to 99.1% of the viruses were inactivated in 24 hours and between [illegible] and [illegible] in 48 hours of anaerobic digestion. This data is presented graphically in *Figure 18*.

In a second study (Bertucci *et al.*, 1975) four enteric picornaviruses were inoculated in pilot anaerobic digesters. *Figure 7* presents the die-away curves for the four viruses studied. After 24 hours of digestion, there was found to be an average of [illegible], [illegible], [illegible] and [illegible] inactivation for poliovirus type 1, coxsackievirus type A-9, coxsackievirus type B-4, and echovirus type 11, respectively. The respective inactivation after 48 hours were [illegible], [illegible], [illegible] and [illegible].

Laboratory studies regarding the die-away of viruses was also conducted by Meyer *et al.* (1971). He used a swine enterovirus [illegible] which has biophysical properties similar to human enteric viruses. After gas production had stabilized in an laboratory digester fed with a mixture of primary and waste activated sludge, they were inoculated with [illegible] plaque forming units of the swine virus. After inoculation, [illegible] ml of fluid was periodically withdrawn from the digester and mixed with milk and fed to germfree piglets. The feces of the piglets were then collected and assayed for viable virus. The virus was not found in the feces of piglets fed sludge material which had been inoculated and digested for a period of time of five days or longer. He concluded that heated anaerobic digestion for 15 days would provide a considerable margin of safety with regard to the destruction of viruses.

One can conclude from these studies that the anaerobic digestion process is highly effective in reducing virus levels in sludge. More work is needed on this aspect of sludge digestion and ultimately the state of the art will advance so that the quantities and types of indigenous viruses can be monitored. However, the available data indicates that concern about virus-caused diseases is not warranted.

There are many opinions about methods to prevent possible public health problems at sludge application sites. Some have even suggested such extraordinary procedures as liming digested sludge to pH 11 for 3 hours [illegible] [illegible] [illegible]. [illegible] pasteurization of digested sludge by heating it to 70°C for 30 minutes has become a widely accepted practice.

Liming of sludge to pH 11 for 3 hours requires the addition of over [illegible] mg/l of lime to digested sludge [illegible], 1971). This dosage [illegible] is based upon laboratory experiments wherein digested sludge ([illegible] total solids) was dosed with varied amounts of lime and the resultant pH was recorded. Adding such quantities of lime to sludge is expensive and significantly increases the amount of sludge to be disposed of. The liming of sludge to pH 11 would add about 10 lbs ([illegible] kg) of lime to every 100 lbs ([illegible] kg) of sludge generated or would increase the sludge to be disposed of by 10%.

Pasteurization of sludge (30 minutes at 70°C) is expensive, costing about [illegible] per dry ton ([illegible]/metric ton) of solids ([illegible], 1971) and is a source of many maintenance problems due to scale buildups on heat exchangers.

It is the opinion of the Metropolitan Sanitary District of Greater Chicago that anaerobic digestion followed by sludge storage are adequate methods of controlling pathogen levels in municipal sludge applied to land. Sludge storage should be 60 days at 20°C or 120 days at 4°C.

The District has conducted studies regarding the fecal coliform die-away resulting from the storage of liquid digested sludge. These studies revealed that, for temperatures averaging about 10°C, fecal coliform in stored digested sludge was reduced from [illegible] cfu/100 ml to [illegible] cfu/100 ml in 33 days.

Table 11 shows the fecal coliform content of stored digester supernatant (liquid portion of the sludge) over a period of [illegible] days. Clearly, the decrease in fecal coliform content is shown quite dramatically.

Berg (1966) suggested also that long term storage was the simplest method for reducing viruses and other pathogen organisms. From laboratory studies, Berg determined the time in days to achieve 99.9% reduction in the number of viruses and bacteria by storage of sewage at different temperatures. The die-away data are presented in Table 12.

It can be seen that storage of sewage for 120 days at 4°C and 60 days at 20°C would be more than adequate in reducing the viruses and bacteria studied by Berg.

In addition to anaerobic digestion followed by storage, the District is strongly in favor of controlling public access to municipal sludge application sites. Such control is not only desirable from the point of view of public health, but also safety.

TABLE 13

FECAL COLIFORM COUNTS OF AN EXPERIMENT CONSISTING OF STORED LIQUID FERTILIZER EXPOSED TO ATMOSPHERIC CONDITIONS [illegible] OCTOBER 24, 1972 THROUGH DECEMBER 15, 1972

DAY SAMPLED	FECAL COLIFORM COUNTS (per 100 milliliters)	DAY SAMPLED	FECAL COLIFORM COUNTS (per 100 milliliters)
0	200,000*	18	1,000
1	1,000**	21	<1,000
2	20,000	22	<1,000
3	6,000	24	500
4	4,000	27	200
7	3,000	28	500
8	10,000	29	600
9	6,000	30	100
10	8,000	31	300
11	4,000	34	<20
14	6,000	35	<20
15	3,000	36	<20
16	3,000	38	<20
17	4,000	41	<20

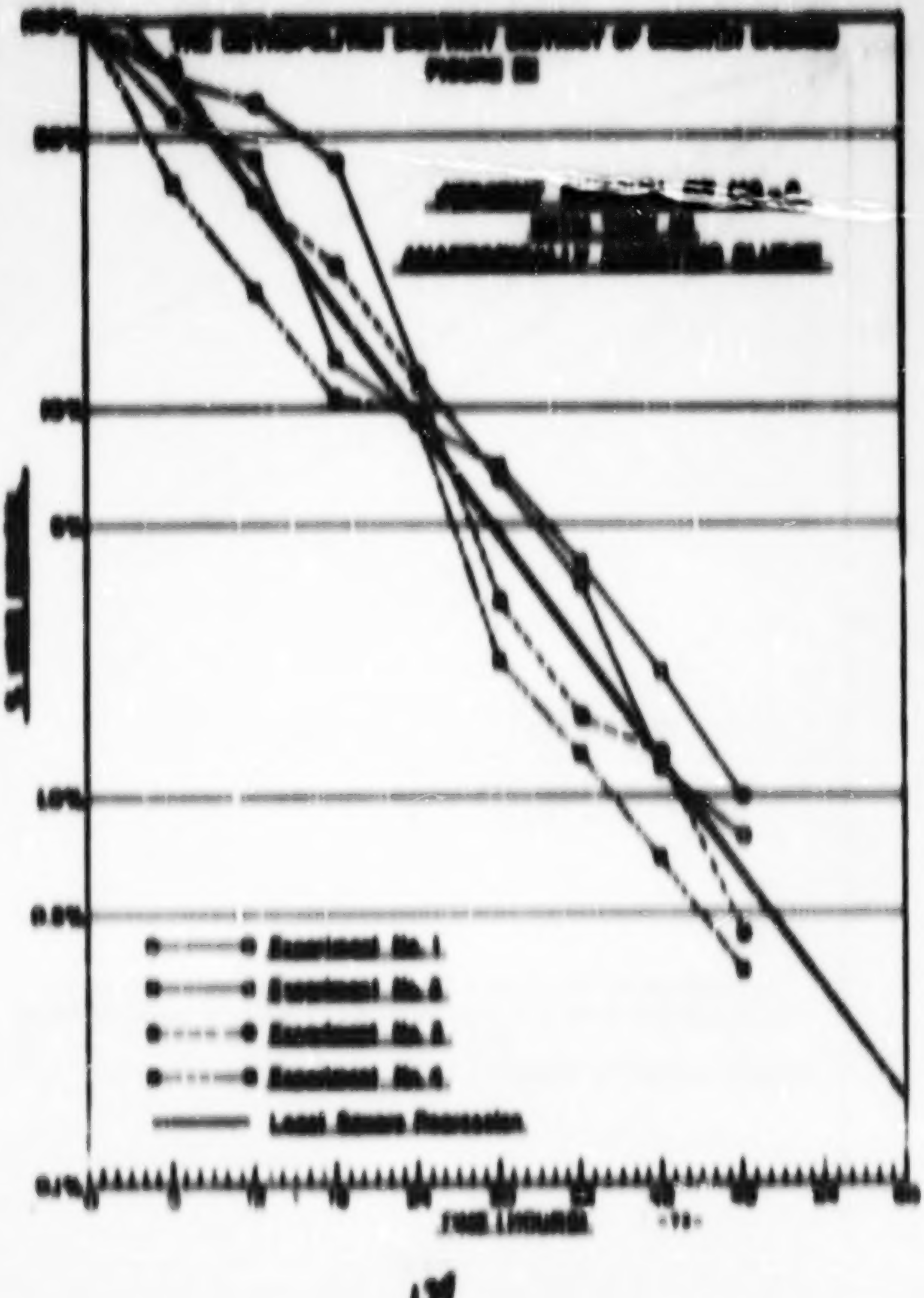
* F.C. count just prior to inoculating

** F.C. count after inoculating

TABLE 14

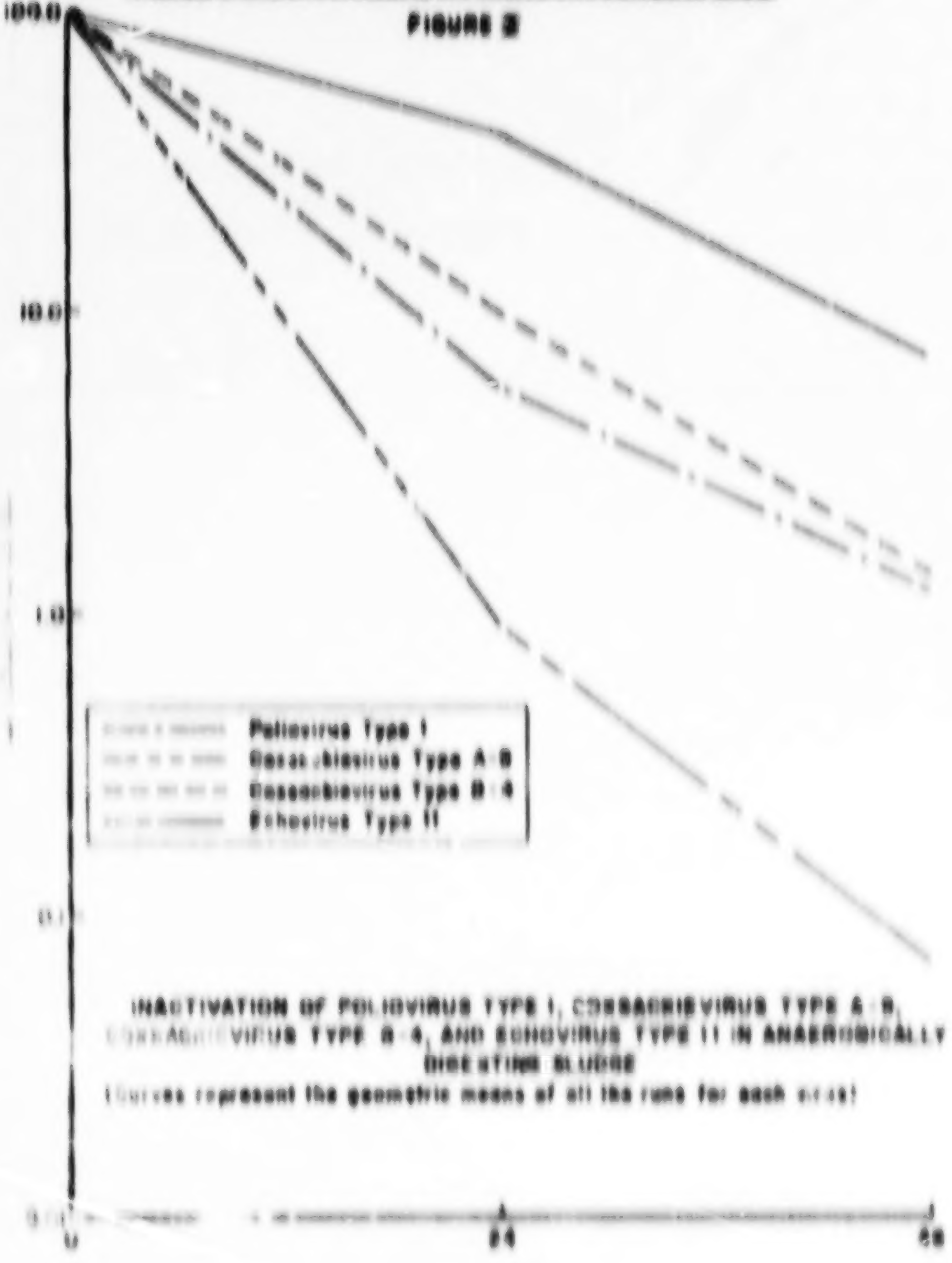
Effects of storage: Laboratory study demonstrating days required for 99.9% reduction of viruses and bacteria in sewage (Berg, 1966).

Organism	No. of Days, Temperature °C		
	4°	20°	28°
Poliovirus 1	110	23	20
Echovirus 7	130	41	28
Echovirus 12	60	32	20
Coxsackievirus A2	12	--	6
Aerobacter aerogenes	56	19	10
Escherichia coli	48	20	12
Streptococcus faecalis	48	26	14


1.0%
0.1%
Experiment No. 1
Experiment No. 2
Experiment No. 3
Experiment No. 4
Least Square Regression

THE METROPOLITAN SANITARY DISTRICT OF GREATER CHICAGO

FIGURE 3



INACTIVATION OF POLIOVIRUS TYPE 1, COXSACKIEVIRUS TYPE A-9, COXSACKIEVIRUS TYPE B-4, AND ECHOVIRUS TYPE 11 IN ANAEROBICALLY DIGESTING SLUDGE

(Curves represent the geometric means of all the runs for each virus)

[illegible]

[illegible]

[illegible]

[illegible]

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TABLE 17

COSTS FOR SLUDGE MANAGEMENT SYSTEM-MSDGC FULTON COUNTY ILLINOIS OPERATIONS (Interest Rate 5 7/8%, cost in 1975 Dollars).***

Sludge Management System Component	Capital Costs Amortized $/Wet Ton	O & M Costs Annual $/Wet Ton
1. Flotation Concentration Digestion	0.70	1.80
2. Transportation (barge 200 miles)	Contractual Agmt.	3.10
3. Holding Basins	0.07	*
4. Land	0.10	**
5. Site Preparation	0.09	*
6. Application System	0.01	1.00
7. Monitoring	0.09	0.06
TOTAL COST : $6.75/W.T.		

* No operating costs assumed. These costs are included in application O & M costs

** Not applicable

*** Engineering News Record Index : 2500

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THE DEPENDENCE OF DEWATERING PROCESS ON AQUEOUS PROPERTIES OF SLUDGES

by
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V[illegible]

The interaction of solid phase, which forms a basic structure of sludge, with liquid phase and basic relationship, defining its passage through sludge, may be shown at consideration of dewatering process in general as liquid penetration through porous mediums by the action of external forces.

According to Darcy-Weisbach Equation for pressure gradient at laminar liquid flow through porous medium the following relationship is true:

$$\frac{\Delta P}{\ell} = \lambda \frac{1}{d} \rho u^2 \quad (1)$$

where ΔP – pressure differential
ℓ – height of specimen
λ – coefficient of resistance
d – characteristic linear parameter for porous media
ρ – density of liquid
u – average flow rate through medium

The relationship of λ to Re may be expressed as

$$\lambda = \frac{C}{Re} \quad (2)$$

in which

$$Re = \frac{u d \rho}{\mu} \quad (3)$$

where C – a number, constant for a given system of characteristic parameters
μ – viscosity of liquid

The actual value of flow rate through pore channels may be found from equation (1) taking into account Equations (2) and (3)

$$u = \frac{d^2}{C} \frac{1}{\mu} \frac{\Delta P}{\ell} \quad (4)$$

The average actual value of flow rate through pore channels in case Darcy's law is true, is given in Equation (4). Darcy's Law itself may be written in the form

$$W = K_n \frac{1}{\mu} \frac{\Delta P}{\ell} \quad (5)$$

where
W – filtration rate
K_n – coefficient of permeability

The relation between actual average flow rate and filtration rate for porous medium, where only part of its area participates in filtration process, may be expressed by the following relationship

$$u = \frac{W}{m_a} \quad (6)$$

m_a – active porosity

A comparison of Equations (4) and (5), considering equation (6) results in

$$\frac{d^2}{C} = \frac{K_n}{m_a} \quad (7)$$

Then

$$K_n = \frac{m_a d^2}{C} \quad (8)$$

Taking relations of certain geometric values such as total porosity and specific surface area as characteristic linear parameter for porous medium, we'll obtain

$$d = \frac{m}{s_a} \quad (9)$$

In accordance with modern hydrodynamics theory (1) then Equation (2) becomes

$$\lambda = \frac{5.1}{Re} \quad (10)$$

Taking into consideration relationships expressed by equations (9) and (10), the following equation will be true

$$K_n = \frac{m_a d^2}{C} = \frac{m_a m^2}{5.1 \, S^2} \quad (11)$$

Relationship (16) determines value of coefficient of permeability, characterizing filtration capacity of porous medium and therefore complex of hydrodynamic properties and physical-chemical phenomena occurring at boundary of liquid-solid phases.

Interaction between solid and liquid phases at the boundary is a determining factor both in the formation of various categories and forms of bonds of liquid with the basic structure of sludge and in the destruction of these bonds as affected by this or that dewatering process.

Using works by Rebinder P.A. (2), Lykov A. V. (3), (4), (5), Kasatkin M. Ph. (6) the author carried out investigations (7), the results of which required more accurate definition according to Rebinder classification of categories of chemically combined water. It was separated into two types: osmotic proper and entrapped by the basic structure of the sludge. The introduction of entrapped water into this classification allowed to create the uniform method for calculation of physical constants related to water balance, structural and filtration characteristics as well as the degree of sludge thickening, which is obtained at this or that unit after handling.

Actual values, calculation equations and consequence of calculations of the whole complex of characteristics are presented in Tables 1, 2, 3, 4 and 5.

Some filtration characteristics and limit residual moisture contents obtained by calculation according to the author's method and by sludge filtration tests according to other investigators, are given in Tables 6 and 7.

Suggested method of investigation of sludge aqueous properties is applied to any two-phase "solid-liquid" system under conditions of their isotropy.

Taking into consideration that a great number of materials in nature and technics is isotropic two-phase solid-liquid systems, the developed method can find a wide application in water and waste water treatment as well as in adjoining fields of science and technics.

TABLE 1

Nature of bond	Physical-mechanical bond			Physical-chemical bond					
				Osmotic Water			Adsorbed Water		
Category and type of bonds	Total amount of water in sample	Free water	Water in macropores $r > 10^{-5}$ cm	Osmotic proper	Entrapped	Micropores $r < 10^{-5}$ cm	Polymolecular adsorption	Monomolecular adsorption	Total amount of adsorbed water
	1	2	3	4	5	6	7	8	9
Symbols for water weight differentiated on category and type of bonds	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

TABLE 2

PHYSICAL CONSTANTS			
Specific weight of liquid phase	Specific weight of solid phase	Volume of specimen	Total surface area of pore volumes in sample
10	11	12	13

TABLE 3

STRUCTURAL CHARACTERISTICS				
Total porosity	Active porosity	Total surface area of pore volumes in sample		Characteristic fabric parameter
		in micro porous systems	in macro porous systems	
14	15	16	17	18

TABLE 4

Basic filtration characteristics			
Coefficient of permeability	Specific resistance		Coefficient of filtration
	Volume	Weight	
19	20	21	22

TABLE 5

Mechanism of water removal	Separation during thickening process	Compression of basic structure without deformation	Compression of basic structure with its deformation	Change in water aggregate condition
Symbols for removed water				
Dewatering process during which a certain category of water is removed	gravity thickening	Vacuum filtration	Pressure filtration or centrifugation	Heat drying

TABLE [illegible]

Type of investigated sample	Calculated values, obtained by author's method		Experimental values of filtration characteristics obtained by other investigators		
	Specific resistance r_0	Coefficient of filtration K_f	Specific weight resistance r_0	Coefficient of filtration K_f	Name of author
1	2	3	4	5	6
[illegible] sand		[illegible]		[illegible]	[illegible] [illegible] (VNII VODGEO)
Sludge from filtration plant At [illegible] concentration [illegible]					
[illegible]	[illegible] 10^{10}		[illegible] 10^{10}		[illegible] (VNII VODGEO)
[illegible]	[illegible] 10^{10}		[illegible]		
[illegible]	[illegible] 10^{10}		[illegible] 10^{10}		
Sludge from [illegible] plant					
Sludge moisture*					
[illegible]	[illegible] 10^{10}		[illegible] 10^{10}		
[illegible]	[illegible] 10^{10}		[illegible] 10^{10}		[illegible]
[illegible]	[illegible] 10^{10}		[illegible] 10^{10}		[illegible]
[illegible]	[illegible] 10^{10}		[illegible] 10^{10}		[illegible]
[illegible]	[illegible] 10^{10}		[illegible] 10^{10}		(VNII VODGEO)
[illegible]	[illegible] 10^{10}		[illegible] 10^{10}		
[illegible]	[illegible] 10^{10}		[illegible] 10^{10}		
[illegible] clay moisture**		[illegible]		[illegible]	[illegible] V. P.
[illegible]				[illegible]	[illegible] V. [illegible] (VNII VODGEO)
[illegible]		[illegible]			
[illegible]		[illegible]		[illegible]	
[illegible]		[illegible]		[illegible]	
Clay from [illegible] moisture**		[illegible]		[illegible]	
[illegible]		[illegible]		[illegible]	

*Moisture = 100% [illegible]

**Moisture in 100% [illegible]